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GLOBAL CLIMATE CHANGE

HEARING

BEFORE A

SUBCOMMITTEE OF THE

COMMITTEE ON APPROPRIATIONS

UNITED STATES SENATE

ONE HUNDRED FIRST CONGRESS

SECOND SESSION

SPECIAL HEARING

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GLOBAL CLIMATE CHANGE

THURSDAY, FEBRUARY 8, 1990

U.S. SENATE,
SUBCOMMITTEE ON VETERANS AFFAIRS, HOUSING AND URBAN DEVELOPMENT, AND INDEPENDENT AGENCIES,
COMMITTEE ON APPROPRIATIONS,
Washington, DC.

The subcommittee met at 10:05 a.m., in room SD-316, Dirksen Office Building, Hon. Barbara A. Mikulski (chairperson) presiding.

Present: Senators Mikulski, Kerrey, Garn, Grassley, and Nickles.

EXECUTIVE OFFICE OF THE PRESIDENT

OFFICE OF SCIENCE AND TECHNOLOGY POLICY

STATEMENT OF D. ALLAN BROMLEY, DIRECTOR

OPENING REMARKS

Senator MIKULSKI. The subcommittee will now come to order. It is an official session. Today, we would like to welcome Dr. Bromley, and his able staff, to the first of our hearings on the 1991 budget.

In addition to focusing on agency by agency, we hope, over the course of the year, to look at the purpose of what we are spending our money on, and, therefore, we are going to focus on the topic today of global warming.

This could be considered one of the hottest planetary issues of 1990, and the approaching new millennium. We welcome the President's Science Advisor, Dr. Bromley, in his first appearance before the subcommittee, to help us clarify the administration's research and policy positions in this area.

The President's 1991 budget proposes spending over $1 billion on global climate change research in seven different Federal agencies, an increase of 57 percent over last year's level, and about three-quarters of these funds will go to agencies within the subcommittee's jurisdiction.

That's why, Dr. Bromley, because you are essentially the President's point person, I believe, in coordinating the research, we wanted to talk with you, in the sense of a unified way, and look at the problem that we are trying to solve, rather than the agency that we are trying to fund.

I think that if we focus our resources that way, we will end up solving some problems. While this research agenda is commendable for its scope and detail, it comes at a time when there is increasing concern that U.S. policy and global climate change is adrift.

First, just as the funds for basic research on climate change are going up, the President has actually proposed cutting EPA's policy research on global change by 40 percent.

While only a modest reduction the total amount of funds, it is an important symbolic action, because it was EPA's missionary policy research that was the foundation of the President's tree planting initiative to get carbon out of the atmosphere.

In addition, there is a great concern in light of the President's speech on Monday to the international organization as to whether the administration is still committed to previous international commitments it made on global warming policy.

Last November, following the Dutch Ministerial Conference, the President announced that the United States would join 70 other countries in stabilizing CO_2 emissions and other greenhouse gases as soon as possible.

Since then, however, the administration has set up no timetable to implement the policies to fulfill this pledge. In fact, this weekend we learned that there is no clear policy now in place on CO_2 emissions.

Because of the conflict that seems to be among the President's advisors and their policy, I hope that we have not missed the opportunity to be preeminent in this endeavor throughout the world.

Perhaps most troubling in the President's speech was that it lacked any sense of urgency on the need to develop both a short-term and long-term policy on global warming other than beyond doing more research.

This Senator has a great respect for research, and good science should lead to good policy, but good science shouldn't lead to a delay in policy. This tone was in striking contrast to some of the President's own previous statements, where he promised to tackle this issue quickly and directly.

This reluctance comes at a time where there seems to be a consensus emerging among the President's science advisors on the need to establish a change—a global climate change policy.

I think that I could go on reading this, but essentially what we want to do is find out what you see in the world of research, and what you see in policy, and then where is essentially the believers of power and initiative to move science to policy, and policy to action.

Dr. Bromley, I really look forward to working with you, sir, and I noted that in a meeting the President has just said that he wants to have a kind of council of wise scientists to advise him, almost like economic advisors; and he has asked you to pull that together.

I know the President's style is that he likes to get a group together, bat around ideas, and get a sense of it, and that he is looking for this same kind of scientific exchange as he would from the people in the field of military strategy. Am I right in that?

Dr. **Bromley**. Absolutely.

Senator **Mikulski**. Well, we look forward to this, because I happen to believe that the science advisor should have the same status in the Presidential orbit as the National Security Advisor, because yesterday was history.

It is something that the people of our generation just never thought would happen. Now, if we could seize a day, and become preeminent in science, as we have been in protecting the free world, boy, what a new century, and so we look forward to hearing from you.

SUMMARY OF STATEMENT

Dr. **Bromley**. Thank you very much, Madam Chair. I really welcome this opportunity to come to talk with you about this important topic of global warming. I think I need hardly tell you, or any other member here that the human race is embarked on an enormous, unplanned planetary experiment in this area—one that poses unprecedented challenge to our scientific understanding, and our societal foresight.

GREENHOUSE EFFECT

The greenhouse effect, which is really what we are talking about here, is really nothing new. Without carbon dioxide and water vapor in the atmosphere, the Earth's surface would have been at a temperature where much of the oceans would have frozen, and life as we know it would have been quite impossible.

But since the beginning of the Industrial Revolution back around 1760, though actually you can take it closer to about 1850, we have significantly changed the composition of the planet's atmosphere by burning fossil fuels, by cutting down our forests to greatly expand agriculture, and by producing industrial chemicals, like the chlorofluorocarbons.

The release of all these materials into the atmosphere, Madam Chair, is the largest impact that our race has had on this planet by a very large margin. We have dumped some 315 billion tons of carbon alone into the atmosphere since 1850, primarily from burning fossil fuels, and from portland cement manufacturing; those are the two dominant sources.

BACKGROUND INFORMATION

Let me try to put this perhaps in a little better perspective. On the average, every human being on our planet releases about a ton of carbon, in the form of carbon dioxide, into the atmosphere each year.

Senator **Mikulski**. Just by breathing?

Dr. **Bromley**. By breathing and by supporting their life, with cooking fuels, and using electricity, and so on; all of these things contribute to the total load, and over the past two centuries, or a little less, the amount of carbon dioxide, which is really a very powerful greenhouse gas, has increased by 25 percent.

When scientists a couple of centuries ahead look back on us, they may think that the most important single piece of data that was obtained in our century was that marvelous curve taken from the top of Mauna Loa, in Hawaii, that shows the growth of carbon dioxide, a more or less linear growth with a superimposed annual fluctuation. That is a vitally important piece of data.

Now, it is also true that way back in 1896, the Swedish scientist, Arkenius first—and more as a back-of-the-envelope calculation—predicted that if we doubled the amount of carbon dioxide in the atmosphere we would raise the temperature by 8 degrees Centigrade.

This is not all that different from some of the model predictions that we have today, but one of the things that I think really triggered public interest, worldwide, in the whole question of global change is the fact that 6 of the hottest 10 years in the century thus far have been in the 1980's.

WARMING TREND

Actually, the trend began sometime about 1880, and by the 1930's, most people thought that we had indisputable evidence that the temperature of the Earth was rising, but then from 1940 until close to 1970, the temperature actually tended to go down more or less linearly, and then turned around since that time, and has been increasing again.

That is a key to the problem that we face, Madam Chair, we really have been unable, thus far, to separate with certainty the man-made component of temperature change from the natural variability.

We also have some problem with uncertainties that surround the temperature records back over the past century. Some are of much better quality than others, but to give you a bottomline statement, with which most scientists would agree, if we continue to put greenhouse gases into the air as we have done in the past, then we will eventually get global warming.

When we get it is not so certain. How large it will be is again not so certain, but I want to emphasize that these issues are extremely important to the President, and they are very important to me, and I want to go back to an impression that you quite correctly noted, Madam Chair.

CURRENT ADMINISTRATION ACTIVITIES

The impression is that the Bush administration is doing less than other countries in responding to global change and to environmental problems. I would like to argue this morning that this impression is entirely mistaken.

If we measure progress here in terms of concrete actions, we will find that the United States is ahead of any other country, in terms of our efforts to understand and to respond to the question of global warming.

A crucial factor in all of this is our attempt to understand the Earth, and the human role on it from a systems point of view, and I feel that it is critically important that the administration work closely with you and your colleagues in the Congress, to develop a well-articulated, and soundly based research program as well as a response program that, in fact, will do what I think that all of our citizens would like to see happen.

We first of all have to understand as much as we can about the science and about the economics involved. Economics is very important, and it was tended not to get into the argument very much until now.

But I agree with you. We must act, and we can't simply sit around and delay, but we are acting, and I will come back to that later. I believe that we are taking very appropriate and concrete actions.

UNDERSTANDING GLOBAL CHANGE

My Office is charged, as you know, Madam Chair, with reviewing and analyzing issues that don't fit neatly into any particular science or technology, or indeed any agency, and global change is a marvelous example of just such a topic that cuts across all of these boundaries, and is no respecter whatsoever of national or international boundaries.

We have seen this emphasized, for example, at the Intergovernmental Panel on Climate Change [IPCC] meeting here in Washington earlier this week—as you noted—and our OSTP coordinating function is carried out, and has been carried out during the past 18 months, from a scientific point of view, primarily by the Committee on Earth Science [CES].

This Committee is under the very able chairmanship of Dr. Dallas Peck, Director of the U.S. Geological Survey. The Committee meets under the Federal Coordinating Council for Science, Engineering, and Technology [FCCSET], of which I am the Chairman.

CES has two subcommittees, one that works on global change and is chaired by Dr. Robert Corell, of the National Science Foundation, and a new one that I have just put together to consider the consequences of global change. I have become convinced that, worldwide, most of the activity in this field has been focused on the input side of the global change question: How do we get global change, when does it arrive, how big is it, and so on, with relatively little effort devoted to the other side of the question; namely, What would happen if such global change were to take place, what would it do to agricultural productivity, to weather patterns, to severe storms, to sea levels, and to all of those things that we must understand if we are going to be able to achieve an economic quantification of what we are dealing with now and in the possible future.

I would like to submit for the record, Madam Chair, this little document that has been produced by the Committee on Earth Sciences to accompany the President's fiscal year 1991 budget; it is entitled "Our Changing Planet—The FY 1991 Global Change Research Program."

Senator **Mikulski**. Without objection, it is so ordered.

Dr. **Bromley**. Thank you.

[The document follows:]

Our Changing Planet:

The FY 1991
U.S. Global Change Research Program

A Report by the Committee on Earth Sciences

To Accompany the
U.S. President's Fiscal Year 1991 Budget

Office of Science and Technology Policy
Federal Coordinating Council for Science, Engineering, and Technology

Committee on Earth Sciences

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EXECUTIVE OFFICE OF THE PRESIDENT
OFFICE OF SCIENCE AND TECHNOLOGY POLICY
WASHINGTON, D.C. 20506

MEMBERS OF CONGRESS:

I am pleased to forward with this letter "Our Changing Planet: The FY 1991 U.S. Global Change Research Program," a report by the Committee on Earth Sciences of the Federal Coordinating Council for Science, Engineering, and Technology to accompany the President's Fiscal Year 1991 Budget.

The report outlines an accelerated, focused research strategy designed to reduce key scientific uncertainties and to develop more reliable scientific predictions upon which sound policies and responses to global change can be based. Because of the importance of this area, the President is proposing a 57 percent increase in the budget for this effort for FY 1991.

The research program presented here is a key component of the President's overall approach to the global change issue. This approach has, as its central goal, the provision of a sound scientific basis for developing national and international policy on global change. The President has called for an expanded schedule of international collaboration on research, monitoring, data exchange, and a new Framework Convention on climate change. This comprehensive approach recognizes the profound economic and social implications of responding to global environmental changes and maintains U.S. leadership on this issue.

The Committee on Earth Sciences' report outlines a careful blend of ground- and space-based efforts in research, data gathering, and modeling activities with both near- and long-term scientific and public policy benefits. The report has benefited from close interaction with the National Academy of Sciences, the International Council of Scientific Unions' International Geosphere-Biosphere Programme, and the World Meteorological Organization's World Climate Research Programme. As such, I believe the report and the process which produced it provide an exemplary model of a coordinated, integrated research strategy and a sound basis for planning. Chairman Dallas Peck, Vice Chairman Robert Corell, and their interagency committee members, associates, and staff have done an excellent job and are to be commended.

Sincerely,

DAllan Bromley

D. Allan Bromley
Director

Executive Summary

- Although the Earth has been changing for millions of years, dramatic recent changes such as antarctic ozone depletion demonstrate that human activities are affecting the Earth system.

- Recognizing the profound economic and social implications of responding to global environmental changes, the President has set in motion a comprehensive process designed to continue U.S. leadership on this issue. This includes an accelerated, focused research effort; active participation in international collaborative efforts intended to culminate in a Framework Convention; and a comprehensive review of potential policies and their implications.

- As the research component of this process, the U.S. Global Change Research Program is designed to reduce key scientific uncertainties and to develop more reliable scientific predictions upon which sound policy strategies and responses can be based.

- An improved predictive model of the integrated Earth system and a better understanding of human interactions with this system will provide direct benefits by anticipating and planning for impacts on commerce, agriculture, energy, resources utilization, and human safety.

- Because of the high priority attached to the U.S. Global Change Research Program, the President is proposing $1,034 million for this research effort in the FY 1991 budget, a $374.8 million or 57 percent increase over the FY 1990 level.

- This proposed budget will significantly expand research, data gathering, and modeling activities with both near- and long-term scientific and public policy benefits. It includes a carefully balanced mix of ground- and space-based research efforts that are essential given the variability of the phenomena being studied and the need to scale local processes to regional and global levels.

- For the ground-based program, the proposed budget will initiate multi-agency research thrusts in several critical areas, including the role of clouds in controlling climate, fluxes of greenhouse gases, resource responses to global change, past changes in the Earth system, and the role of human activities in global change.

- For the space-based program, the proposed budget will initiate the development of the NASA Earth Observing System, a key element in "Mission to Planet Earth," which will provide the centerpiece of an integrated international satellite program for monitoring global change, coupled with a comprehensive data and information system.

- This report summarizes the key features and budget of the proposed U.S. Global Change Research Program for FY 1991. A more detailed FY 1991 research plan will be released in the spring of 1990.

- The research program was developed by the Committee on Earth Sciences of the Federal Coordinating Council for Science, Engineering, and Technology, in close interaction with the National Academy of Sciences, the International Council of Scientific Unions' International Geosphere-Biosphere Programme, and the World Meteorological Organization's World Climate Research Programme.

Introduction

World leaders are taking an increased interest in the economic and social implications of global environmental changes, both natural and human-induced. The 1988 midwestern U.S. drought underscored the potential effects of a warm, dry summer, just as the climate in recent decades in the Sahel starkly reveals the human tragedy that can occur in marginal-subsistence zones of a changing planet. Furthermore, the very recent linking of the antarctic ozone "hole" to man-made chlorofluorocarbons and the current debate over humanity's role in the greenhouse effect have placed the environment high on the national and international agenda.

In virtually all of these issues, the salient feature is the significant scientific uncertainty associated with predicting the behavior of the coupled ocean-atmosphere-land system. The formidable costs associated with addressing environmental change require that policy decisions be based on adequate scientific knowledge. To provide this knowledge, the U.S. Global Change Research Program has been created as a key component of the President's overall approach to global environmental change. Because of the priority attached to this issue, the President is requesting $1,034 million for the research program in FY 1991, an increase of $374.8 million or 57 percent over the FY 1990 level.

The present document is the second in a series of overviews that accompany the President's annual budget to the Congress. It highlights the Program's FY 1991 research activities and budget developed by the Committee on Earth Sciences (CES) of the Federal Coordinating Council for Science, Engineering, and Technology.

The CES activities of the past year began with the publication in January 1989 of *Our Changing Planet: A U. S. Strategy for Global Change Research.* Following this strategic plan, the CES prepared *Our Changing Planet: The FY 1990 Research Plan* (July 1989), which reviewed the Earth system changes that have occurred in the past; the forces that are at work today;

and the strengths and weaknesses in current scientific understanding. It also described the highest priority interdisciplinary research needs, agency roles, and new FY 1990 research initiatives.

The FY 1990 Research Plan was reviewed by the National Academy of Sciences, the American Geophysical Union, and others, all of whom strongly endorsed the Program's holistic approach to understanding the Earth system. The *Plan* is also consistent with the concepts outlined by the International Geosphere-Biosphere Programme and the World Climate Research Programme.

While recognizing the need for a comprehensive research and modeling effort, the FY 1991 Program also focuses on the scientific issues underlying current and future policy questions, including: Should the "Montreal Protocol on Substances that Deplete the Ozone Layer" be strengthened? Has a global warming signal been detected, and what are the relative contributions from natural processes and human activities? What will the climate of the coming century be like, and how will it impact agriculture, forestry, habitation, and water and energy supply and use?

Furthermore, the present document shows how this integrated interdisciplinary program has begun to address such crosscutting activities as understanding the carbon cycle, data management, education, and emerging disciplines.

A comprehensive FY 1991 research plan will be published in the spring of 1990.

Planning the FY 1991 Program

In *The FY 1990 Research Plan*, the CES established the following goal and objectives for the U.S. Global Change Research Program:

Goal:

To establish the scientific basis for national and international policymaking relating to natural and human-induced changes in the global Earth system.

Objectives:

To establish an integrated, comprehensive long-term program of documenting the Earth system on a global scale.

To conduct a program of focused studies to improve our understanding of the physical, geological, chemical, biological, and social processes that influence Earth system processes and trends on global and regional scales.

To develop integrated conceptual and predictive Earth system models.

Planning Framework

Each year the CES will review the Program to ensure that it continues to aggressively address its goal and objectives. This process began in mid-July 1989, when CES evaluated individual agency initiatives relative to ongoing programs and the priority and evaluation framework outlined later in this section.

At a series of meetings over the ensuing months, agency representatives developed a final recommendation on the content and resource requirements for the FY 1991 Program. Subsequently, during the fall of 1989, there were extensive program reviews and discussions that led ultimately to the FY 1991 Program and budget summarized herein.

As part of these deliberations, the CES has forged increasingly effective partnerships among the Federal agencies and with the scientific community. These partnerships, the need to integrate science into the policy process, and the focus on interdisciplinary science have become the "Basic Tenets" (see box on page 7) of the CES cooperative planning process.

Priority Framework

In the preparation of *The FY 1990 Research Plan*, the CES created and implemented a multi-level priority-setting framework that was used to focus and integrate the program development and budget proposals. This framework contains three levels of priorities for the U.S. Global Change Research Program, diagrammed in Figure 1. These strategic, integrating, and science priorities focus on those research questions that will produce significant early improvements in understanding and modeling the interactive Earth system. For example, there is little disagreement that a major shortcoming of existing general circulation models is their inability to simulate the role of clouds and convective processes accurately; hence, that research is the highest priority in the Climate and Hydrologic Systems element. However, concurrent progress in high priority activities in all science elements is necessary for the Program to achieve its overall goal, although not all will receive equal emphasis.

Evaluation Criteria

Within each science element, the CES evaluated FY 1991 research initiatives, taking into account the priorities and several evaluation criteria (see box on page 10). These criteria provided a framework for designing the specific project-by-project structure that constitutes the Program (see Appendix for project listing).

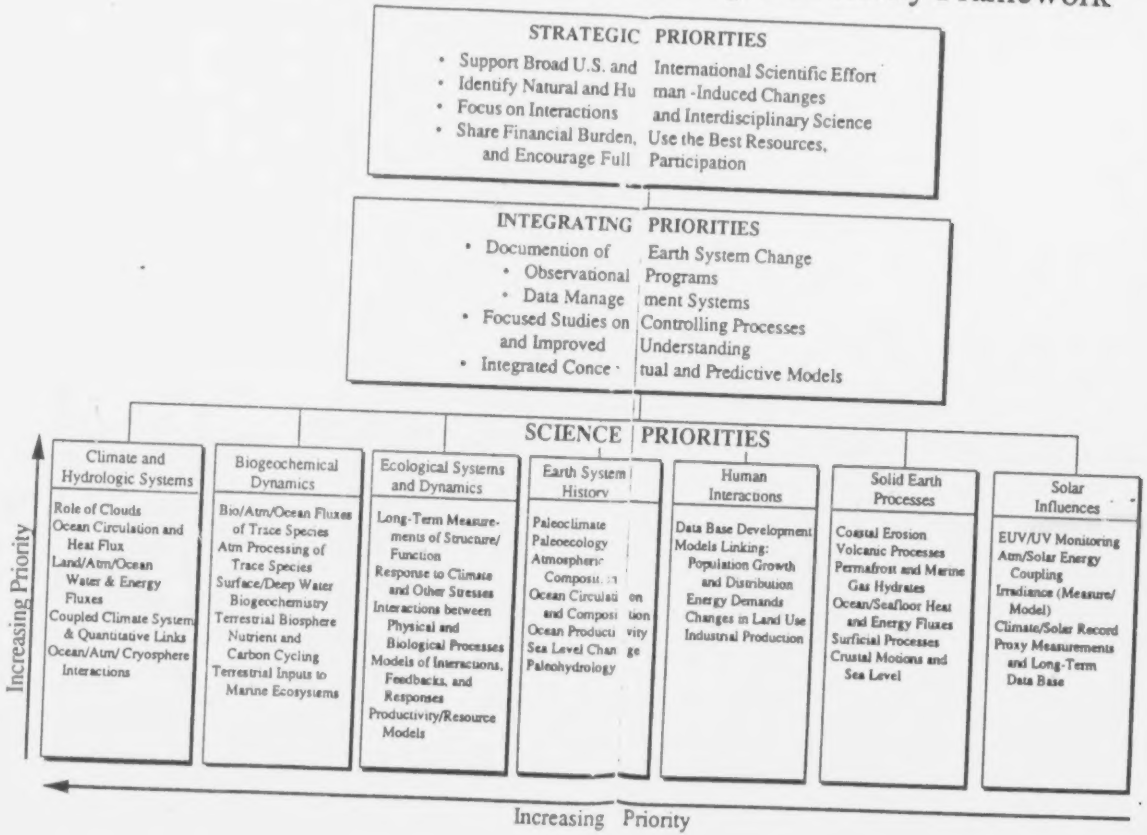
The CES Process: Basic Tenets

- ***Integrate Science into the Policy Process.*** The need for effective relationships between the policy processes of governments and the underlying science of environmental issues has always been recognized and central to the U.S. Global Change Research Program. A process for policy development has evolved within the Executive Branch that directly involves the CES, including (i) it being the focal point for the development and coordination of U.S. scientific programs for global change, both domestically and internationally, and (ii) ensuring that the results of these scientific efforts provide the foundation for rational policy debate and effective action.

- ***Maintain a Partnership Among All Participants.*** A partnership has evolved among the CES members and between CES and the non-Federal research community through the relevant Committees and Boards of the National Academy of Sciences (NAS), notably the Committee on Global Change (CGC). Within CES, there has been a conscious effort not to designate "lead" agencies. Leadership is distributed among the agencies, with each contributing its strengths to the planning, documentation, review, and implementation process. This partnership concept is fundamental to the operation of the CES. The same philosophy is operative in the parallel planning relationship with the NAS, including joint meetings, program reviews, and exchange of ideas for developing implementation strategies. In addition, the CES has interacted with (i) the international scientific community and agencies of other governments, (ii) several intergovernmental bodies with global change concerns, (iii) the environmental community, and (iv) the private sector.

- ***Focus on Interdisciplinary Science and Interactions.*** The CES science program is founded on the premise that the essential scientific questions can only be addressed through interdisciplinary research on the interacting components of the Earth system. This is also the scientific strategy of the CGC and its international counterpart, the International Geosphere-Biosphere Programme (IGBP), thereby further strengthening the interactions of the CES and CGC.

Figure 1
U.S. Global Change Research Program Priority Framework


STRATEGIC PRIORITIES
• Support Broad U.S. and International Scientific Effort
• Identify Natural and Human-Induced Changes
• Focus on Interactions and Interdisciplinary Science
• Share Financial Burden, Use the Best Resources, and Encourage Full Participation
INTEGRATING PRIORITIES
• Documention of Earth System Change
• Observational Programs
• Data Management Systems
• Focused Studies on Controlling Processes and Improved Understanding
• Integrated Conceptual and Predictive Models
SCIENCE PRIORITIES
Climate and Hydrologic Systems
Role of Clouds
Ocean Circulation and Heat Flux
Land/Atm/Ocean Water & Energy Fluxes
Coupled Climate System & Quantitative Links
Ocean/Atm/Cryosphere Interactions
Biogeochemical Dynamics
Bio/Atm/Ocean Fluxes of Trace Species
Atm Processing of Trace Species
Surface/Deep Water Biogeochemistry
Terrestrial Biosphere Nutrient and Carbon Cycling
Terrestrial Inputs to Marine Ecosystems
Ecological Systems and Dynamics
Long-Term Measurements of Structure/Function
Response to Climate and Other Stresses
Interactions between Physical and Biological Processes
Models of Interactions, Feedbacks, and Responses
Productivity/Resource Models
Earth System History
Paleoclimate
Paleoecology
Atmospheric Composition
Ocean Circulation and Composition
Ocean Productivity
Sea Level Change
Paleohydrology
Human Interactions
Data Base Development
Models Linking:
Population Growth and Distribution
Energy Demands
Changes in Land Use
Industrial Production
Solid Earth Processes
Coastal Erosion
Volcanic Processes
Permafrost and Marine Gas Hydrates
Ocean/Seafloor Heat and Energy Fluxes
Surficial Processes
Crustal Motions and Sea Level
Solar Influences
EUV/UV Monitoring
Atm/Solar Energy Coupling
Irradiance (Measure/Model)
Climate/Solar Record
Proxy Measurements and Long-Term Data Base
Increasing Priority
Increasing Priority

The CES Evaluation Criteria

- ***Relevance/Contribution.*** The research must address the overall goal and one or more of the three key scientific objectives of the Program.
- ***Scientific Merit.*** The proposed work must be scientifically sound and of high priority, and be the product of a documented scientific planning and review process.
- ***Readiness.*** The level of planning must be mature, of high quality, and the research likely to produce vital and needed advances.
- ***Linkages.*** The CES looks for established inter-agency, other national, and international connections.
- ***Costs.*** The CES considers whether the identified resources are adequate; if they represent an appropriate share of total available resources (e.g., a balance between space- and ground-based program elements); prospects for joint funding; and the degree to which long-term resource implications have been evaluated.
- ***Enhancements to Existing Program Research.*** The highest priority existing programs will receive adequate support before new initiatives are funded.
- ***Agency Approval.*** The proposed program or activity must have policy-level approval by the submitting agency.

Agency and Organizational Roles

At the outset of the Program, the CES developed a set of role statements that specifically define each agency's respective role in the Program (see *The FY 1990 Research Plan,* Appendix A). In developing the FY 1991 Program, that process of role definition has been extended. The current status of participation in the Program by CES agencies and other Federal organizations has three categories:

(1) ***Agencies whose budget initiatives are in the "focused" category and hence are detailed in this document.*** These are the Department of Commerce, National Oceanic and Atmospheric Administration (DOC/NOAA), Department of Energy (DOE), Department of the Interior (DOI), Environmental Protection Agency (EPA), National Aeronautics and Space Administration (NASA), National Science Foundation (NSF), and the United States Department of Agriculture (USDA).

(2) ***Agencies whose programs fall into the "contributing" category.*** These agencies' programs support many of the science elements, but were initiated for reasons other than the focused Program goal. They include the agencies with focused programs and the research agencies of the Department of Defense (DOD) (including the Office of Naval Research, the Oceanographer of the Navy, and the U.S. Army Corps of Engineers).

(3) ***Agencies and offices of the Executive Branch that contribute to the overall guidance of the Program.*** These agencies and offices contribute to the architecture of the Program and are key vehicles for coordinating and linking the Program with overall national and international policy on global change. These include the Council on Environmental Quality (CEQ), Departments of State (DOS) and Transportation (DOT), Office of Management and Budget (OMB), Office of Science and Technology Policy (OSTP), and the White House Office of Policy Development.

Benefits

The U.S. Global Change Research Program is founded on the premise that effective strategies to address environmental issues can be built only on sound scientific information.

Therefore, a hallmark of the Program strategy is linking the U.S. scientific program for global change to the policy process, including:

- Predicting the magnitude and timing of environmental variations, thereby providing the means to plan or avoid their impacts.
- Separating natural changes from human-induced changes, thereby balancing regulatory needs with economic and social development and providing the ability to focus on those parts of the problem that are traceable to human intervention.

Specifically, this is accomplished by supporting a robust, prioritized research effort that can address important policy issues (see box on page 13) and address public needs for predicting and dealing with environmental change through:

(i) ***Providing Timely Information*** – making available the results of scientific research through special briefings and other information products for the Congress, the Executive Branch, and others immediately after new insights are obtained;

(ii) ***State of the Science Assessments*** – providing periodic assessments of the "state of the science" in the critical areas of global change (as has been done regarding the stratospheric ozone layer), employing both domestic and international mechanisms, such as the Committees of the NAS and the Intergovernmental Panel on Climate Change (IPCC);

Benefits of the U. S. Global Change Research Program: Examples

- ***Greenhouse Gases.*** A better understanding of the processes, both natural and human-influenced, that govern the sources and fates of greenhouse gases will provide a basis for analyzing integrated control strategies and cost-benefit analyses.
- ***Ozone Depletion.*** Maintaining the "Montreal Protocol on Substances that Deplete the Ozone Layer" will require an improved knowledge of the mechanisms controlling the stability of the stratospheric ozone layer.
- ***Energy.*** Establishing links between carbon dioxide emissions and atmospheric abundances with energy policy scenarios will facilitate the assessment of different energy technologies.
- ***Agriculture/Ecosystems.*** Better knowledge of the linkages of crops, forests and other ecosystems to environmental conditions will enhance the ability to make sound decisions regarding food security, forest management, and conservation of natural resources, including crop selection, reforestation, and deforestation practices.
- ***Water Policy.*** A more complete knowledge of the interaction of the climate and hydrological cycles will help resolve issues involving water supply and demand and will allow better planning for the allocation of water resources during extreme events.
- ***Sea Level.*** Elucidation of the processes that control sea level will provide the predictive capability to guide policies regarding coastal human settlements and wetlands.

(iii) ***Regular Prediction/Forecasting Products*** - providing a line of information products that address three time scales: seasonal, interannual, and interdecadal.

- ***Seasonal Projections*** - It is expected that research already under way (including developments from the sciences associated with weather forecasting) will lead to seasonal forecasts (i.e., 30- to 60-day projections) within three to five years. These products will likely be derived from the existing weather forecasting systems operating throughout the countries of the world. Ocean forecasting is in an earlier state of development and will require increased effort to achieve this goal.

- ***Interannual Projections*** - The advent of a greatly improved understanding of how the tropical ocean induces changes in heating patterns within the atmosphere (El Niño and the Southern Oscillation) is leading toward one of the next realizable lines of predictive products. It is expected that within about 10 years regular assessments and forecasts will be produced quarterly, each providing three- to six-month forecasts, a one-year prognosis, and a two-year outlook of interannual climate variability for selected climatic processes.

- ***Interdecadal Projections*** - It is expected that prediction of selected climatic processes on interdecadal (ten to twenty years) time scales will emerge during the coming decade. The products will consist of interpretive reports and model predictions. This process is beginning with the science assessment of the IPCC and the Second World Climate Conference in late 1990.

In summary, the overall benefits of the Program are substantial: (i) providing critical data to minimize economic or other adverse impacts by supporting prudent near-term actions where justified, while accelerating the development of more reliable scientific understanding on which to base long-term policies; (ii) contributing to the Nation's environmental leadership and credibility, both domestically and internationally; and (iii) serving as a catalyst for similar scientific commitments from other nations.

Research Program and Budgets

The following sections summarize the FY 1991 activities and budgets of the U.S. Global Change Research Program in the seven interdisciplinary science elements, by agency, by scientific objective including data management, by Federal budget function, and by the balance between space- and ground-based components. Because of the complex nature of the Program, examples of important research, data collection, and modeling activities will be mentioned along with how they address the research priorities and related policy-relevant questions.

Budget Overview

Table 1 shows the U.S. Global Change Research Program budget proposal by science element, by agency, and by scientific objective. In FY 1990 funding for the U.S. Global Change Research Program is $659.3 million.* The President's FY 1991 budget proposes a funding level of $1,034 million, a $374.8 million (57 percent) increase over the FY 1990 level. Table 2 shows the budgets for programs that contribute to global change research and provide important support to the Program objectives but were initiated for reasons other than the focused Program goal.

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* The FY 1990 Program as outlined in the President's FY 1990 Budget to Congress was $190.5 million (see *Our Changing Planet: A U.S. Strategy for Global Change Research*, January 1989). The FY 1990 Program was adjusted to $659.3 million over the past year reflecting subsequent FY 1990 Appropriations actions by the Congress and the reevaluation of "focused" and "contributing" programs. The bulk of this increase is due to the transfer of several NASA programs from the "contributing" category.

Budget by Science Element

This section summarizes the FY 1991 activities in the seven interdisciplinary science elements and data management. Figure 2 shows the FY 1990 enacted and FY 1991 proposed budgets for the U.S. Global Change Research Program by science element. At this time the U.S. Global Change Research Program focuses primarily on the three highest priority science elements: Climate and Hydrologic Systems, Biogeochemical Dynamics, and Ecological Systems and Dynamics. However, the Program maintains an appropriate level of effort in all seven science elements consistent with the policy needs, science priorities, and the current state of scientific program development.

Figure 2
U.S. Global Change Research Program Budget by Science Element

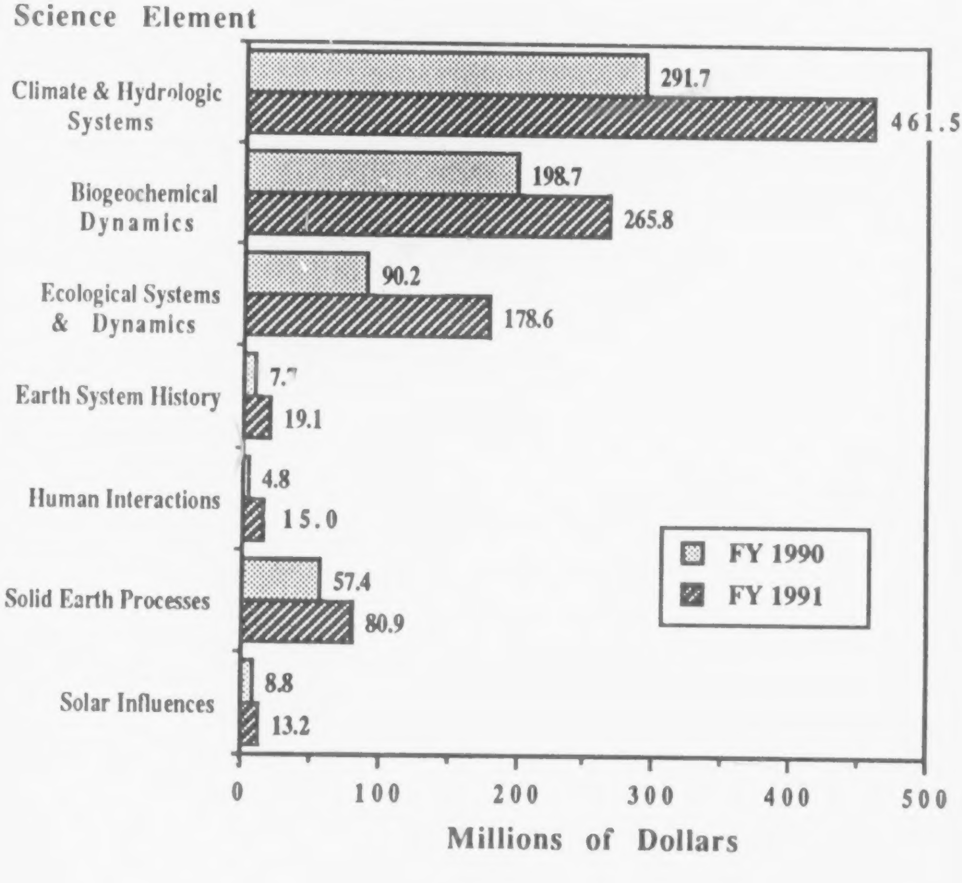


Table 1
FY 1990-1991 U. S. Global Change Research Program Focused Budget
(Dollars in Millions)

Focused Program	Total Budget		Climate & Hydrologic Systems		Biogeochemical Dynamics		Ecological and	Systems Dynamics	Earth System History		Human Interactions		Solid Earth Processes		Solar Influences	
	FY90	FY91	FY90	FY91	FY90	FY91	FY90	FY91	FY90	FY91	FY90	FY91	FY90	FY91	FY90	FY91
Agency Totals	659.3	1034.1	291.7	461.5	198.7	265.8	90.2	178.6	7.7	19.1	4.8	15.0	57.4	80.9	8.8	13.2
DOC/NOAA	18.0	87.0	14.2	67.6	3.3	13.5	0.0	4.9	0.5	1.0	0.0	0.0	0.0	0.0	0.0	0.0
DOE	50.0	66.0	32.0	44.0	7.0	9.0	9.0	10.0	0.0	0.0	2.0	3.0	0.0	0.0	0.0	0.0
DOI	13.3	43.7	4.9	12.2	0.8	2.0	0.9	10.3	2.4	8.0	0.9	5.3	3.4	5.9	0.0	0.0
EPA	13.2	26.0	1.0	3.3	2.5	3.1	9.7	19.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NASA	488.6	661.0	221.4	302.5	162.2	198.3	51.0	90.0	0.0	0.0	0.0	0.0	47.7	63.0	6.3	7.2
NSF	55.0	103.0	16.8	29.8	20.2	32.2	3.5	8.5	4.5	9.0	1.2	5.5	6.3	12.0	2.5	6.0
USDA	21.2	47.4	1.4	2.1	2.7	7.7	16.1	35.3	0.3	1.1	0.7	1.2	0.0	0.0	0.0	0.0
Scientific Objective																
Observations	137.2	255.0	89.1	148.9	17.2	38.9	14.1	39.6	0.0	0.2	0.0	2.2	13.1	20.8	3.7	4.4
Data Management	65.2	129.4	32.9	64.0	21.2	34.7	5.5	17.7	0.5	2.2	0.4	1.0	3.8	8.8	0.9	1.0
Understanding	409.7	560.0	143.1	200.3	148.1	176.2	65.5	103.2	6.1	13.1	2.9	10.6	40.5	50.1	3.5	6.5
Prediction	47.2	89.7	26.6	48.3	12.2	16.0	5.1	18.1	1.1	3.6	1.5	1.2	0.0	1.2	0.7	1.3

Climate and Hydrologic Systems

Table 1 shows that the FY 1991 request for this element is $461.5 million, a $169.8 million or 58 percent increase over the FY 1990 level.

The increasing abundances of greenhouse gases in the Earth's atmosphere are altering the radiative balance of the planet. However, the impact on the climate is uncertain. The response of the Earth's climate is strongly tied to the natural variability of the climate and hydrologic systems, including the atmospheric, oceanic, cryogenic, and land surface processes that govern the distribution of temperature, moisture, clouds, and rainfall. Effective policy formulation requires quantification of the natural and human-induced variability in the climate and hydrologic systems, and reliable predictions of the magnitude and timing of regional and global changes in response to the increasing abundances of greenhouse gases.

The FY 1991 research efforts listed below reflect the Program's research priorities (see Figure 1) and involve the following policy-relevant questions:

(1) *What is the role of clouds in the Earth's radiation and heat budgets?*

Clouds and water vapor play a pivotal role in the Earth's radiation and heat budgets. They control the amount of solar energy absorbed by the climate system as well as the infrared radiation emitted to space, and they strongly influence the redistribution of heat throughout the climate system. A change of a few percent in global mean cloud cover or type could either dramatically enhance or counteract the radiative effects of anthropogenic greenhouse gas emissions.

To understand the role of clouds in controlling the Earth's radiative and heat budgets requires knowledge of their distribution, radiative properties, and cloud-radiation feedback mechanisms. For example, ongoing and new research programs that are focused on this area include: NASA's Earth Radiation Budget Experiment; the NASA, NOAA, and NSF International Satellite Cloud Climatology Project (ISCCP) and associated field campaigns; and a broad range of proposed studies and measurements (NASA's Earth Observing System [EOS] and DOE's Atmospheric Radiation Measurements [ARM] program).

(2) ***How do the oceans interact with the atmosphere in the storage, transport, and uptake of heat?***

The oceans and atmosphere play a vital role in the transport of energy from the equator to the polar regions. The rate at which the oceans exchange heat with the atmosphere controls the magnitude and timing of the predicted global warming due to greenhouse gases.

The prediction of climate change will require ocean observation systems analogous to the existing atmospheric systems used to predict the weather. Understanding the role of the oceans in exchanging energy with the atmosphere requires knowledge of ocean circulation and air-sea energy fluxes.

Numerous ongoing and new research programs contribute to these areas. *In situ* (NOAA, NSF, and DOI) and remote (NASA scatterometer [Earth Probes] and altimeter [TOPEX]) ocean observation systems will contribute to studies of ocean circulation and the coupling of the ocean and the atmosphere. Interannual climate change (Tropical Ocean-Global Atmosphere [TOGA]: NOAA, NSF, and NASA), and the general circulation of the oceans (World Ocean Circulation Experiment [WOCE]: NSF, NOAA, and NASA) are critical investigations. Other key research includes the NOAA Atlantic Climate Change Project, and the proposed new generation of space-based measurements of ocean altimetry, temperature, and wind stress (NASA EOS).

(3) *How will changes in climate affect temperature, precipitation, and soil moisture patterns, and the general distribution of water and ice on the land surface?*

Changes in seasonal temperatures, precipitation and soil moisture patterns could have significant ramifications for water resources, agricultural productivity, natural ecosystems, and the exchange of water between oceans and glaciers.

Understanding the distribution of precipitation and the impacts of a changing climate on the distribution of water and ice on land surfaces requires knowledge of the fluxes of energy and water within the Earth system, water resources on the land, and changes in the area and volume of glaciers.

Ongoing and new research programs that will contribute to these areas include: the Global Energy and Water Cycle Experiment (GEWEX: NOAA, NSF, DOI, and NASA); the proposed new generation of space-based measurements of precipitation, winds, water vapor, clouds, and ice extent (NASA Earth Probes and EOS); long-term observational networks of water resources (DOI, NOAA, and DOE); field and modeling studies of the climate sensitivity of watersheds (DOI and USDA); continental-scale hydrologic processes (NSF and DOE), water budgets in managed and manipulated ecosystems (USDA) and in temperate and arctic regions (DOE); and compilation of glacier extent worldwide, but especially in the Arctic and Antarctic, using ground-based and satellite data (NSF, DOI, and NASA).

(4) *How can the reliability of global- and regional-scale climate predictions be improved?*

Accurate predictions of climate change, whether natural and/or human-induced, are vital for evaluating environmental and socioeconomic impacts. The current generation of climate prediction models is inadequate to confidently predict the magnitude and timing of climate change. This is particularly true at the regional scale.

Improving the reliability of model predictions will require the development of climate diagnostics, model assimilation of climatic data, modeling shorter space and time scales, and an improved parameterization of key Earth system processes.

Ongoing and new research programs that will contribute to these areas include: enhanced climate modeling and diagnostics efforts (NOAA, NASA, NSF, and DOE); mechanistic studies of climatic change through analysis of observations (NOAA and NSF); development of climate modeling data assimilation techniques (NOAA and NSF); a critical review of data needs both for detection of climate change and for climate modeling (DOE); development of regional climate and hydrology models linked to global climate models (EPA and USDA); and the development of the capability to forecast seasonal conditions through coupled ocean-atmosphere modeling and extension of conventional weather prediction techniques (NOAA). Results from a number of process-oriented studies will be utilized to parameterize key interactions in models, including cloud-radiation interactions (NASA, NOAA, NSF ISCCP, and DOE ARM), and land-ocean-cryosphere-atmosphere interactions, including land surface hydrology (NSF, NOAA, DOI, and NASA).

Biogeochemical Dynamics

Table 1 shows that the FY 1991 request for this element is \$265.8 million, a \$67.1 million or 34 percent increase over the FY 1990 level.

There is compelling scientific evidence that the atmospheric concentrations of several key radiatively and chemically active gases are increasing, due both to natural processes and human activities. The rates of increase of these gases depend not only on their emissions, but also on the fate of these gases, which involves the cycling of carbon and other key nutrients between the ocean, atmosphere, and terrestrial biosphere. Currently, there are significant uncertainties in understanding these processes, thus limiting the ability to quantitatively predict future increases in atmospheric trace gas concentrations. This restricts the formulation of effective policies regarding trace gas emissions.

The FY 1991 research efforts listed below reflect the Program's research priorities (see Figure 1) and involve the following policy-relevant questions:

(1) ***What is the relative importance of the oceans and terrestrial biosphere as sinks for fossil fuel carbon dioxide, and how do they change with time?***

Increasing atmospheric concentrations of carbon dioxide are predicted to contribute to global warming. Presently some portion of the emissions from the combustion of fossil fuels and deforestation stay in the atmosphere, with the remainder being taken up by the oceans and the terrestrial biosphere, but the proportions and responsible processes are not well understood. For a given anthropogenic emission scenario, the prediction of atmospheric growth rates of carbon dioxide depend upon an understanding of this sequestering of emitted carbon dioxide.

To understand the relative importance of the oceans and terrestrial biosphere as sinks for fossil fuel carbon dioxide requires knowledge of biogeochemical and physical processes and the fluxes of carbon and nutrients among and between the atmosphere and land and ocean surfaces.

Numerous ongoing and new research programs contribute to these areas. *In situ* studies of the processes responsible for controlling the concentration, distribution, and cycling of oceanic carbon (NSF, NOAA, and DOE), complemented by remote sensing measurements of ocean productivity, sea surface temperatures, and winds (NASA) contribute towards the Joint Global Ocean Flux Study (JGOFS). *In situ* studies of the sequestering of carbon dioxide and the storage and cycling of carbon and other key nutrients within natural and disturbed terrestrial ecosystems (DOI, NSF, EPA, DOE, and USDA) will be complemented by estimates of standing biomass and the biological productivity of terrestrial ecosystems using satellite imagery (NASA EOS).

(2) ***What are the major sources responsible for the current increases in atmospheric nitrous oxide and methane?***

The well-documented increases in the atmospheric concentrations of methane and nitrous oxide are predicted to contribute to global warming, affect stratospheric ozone, and, in the case of methane, to increase tropospheric ozone. The natural and anthropogenic sources of these gases have been qualitatively explained, but not adequately quantified. Hence, effective emission control strategies cannot be formulated.

Understanding current and future trends in the atmospheric concentrations of methane and nitrous oxide requires knowledge of their emissions from industrial and ecological sources; the processes that control their fluxes between the atmosphere, biosphere, and land and ocean surfaces; the impact of changing environmental conditions upon their fluxes; and their atmospheric distribution and transformations.

Many ongoing and new research programs will contribute to these areas including: studies of the fluxes of methane and nitrous oxide, the processes controlling them, and their response to environmental changes from one or more of the key sources, including natural ecosystems, agricultural systems, managed forests, cattle, biomass burning, and gas hydrates (NASA, NOAA, NSF, EPA, DOI, DOE, and USDA); quantification of the areal extent and environmental and ecological conditions conducive to methane and nitrous oxide emissions from terrestrial ecosystems (NASA EOS); atmospheric distributions and trends of methane and nitrous oxide (NASA and NOAA); and the atmospheric distribution and transformations of species (such as tropospheric ozone, hydroxyl radicals, oxides of nitrogen, carbon monoxide, and non-methane hydrocarbons) that control the distribution and lifetime of methane (NSF, NASA, NOAA, DOE, and EPA).

(3) ***What are the implications for stratospheric ozone, globally and in polar regions, of increased concentrations of chlorine and bromine?***

Current scientific understanding indicates that the antarctic ozone hole will seasonally reoccur until the stratospheric chlorine levels decrease by 30 percent from today's level. However, it is not yet possible to quantify, under conditions of enhanced chlorine and bromine concentrations, the impact of the antarctic ozone hole on ozone levels at mid-latitudes in the southern hemisphere or the probability of significant ozone depletion over the Arctic. An improved quantitative understanding of the processes controlling stratospheric ozone, particularly in the polar regions, would allow improved environmental impact assessments to be conducted and improve policy formulation concerning chlorine and bromine containing chemicals, including proposed substitutes.

To understand the response of stratospheric ozone to changes in chlorine and bromine requires knowledge of their fluxes into the stratosphere; the chemical composition and physical structure of the stratosphere; and the coupling between chemical, dynamical, and radiative processes in the stratosphere.

Ongoing and new research programs that will contribute to these areas include: monitoring the atmospheric distribution of the source gases (NOAA and NASA); monitoring the chemical composition and dynamical structure of the stratosphere using a ground-based network of remote sensing, aircraft and balloons, and satellite observations (NASA, NOAA, and NSF); and studying the atmospheric cycling and transformations of compounds that influence the chemistry of the stratosphere (NASA, NOAA, NSF, and EPA).

Ecological Systems and Dynamics

Table 1 shows that the FY 1991 request for this element is $178.6 million, a $88.4 million or 98 percent increase over the FY 1990 level.

Ecological systems are important in global change research for two principal reasons. First, changes in climate, atmospheric composition, and solar radiation can affect the productivity, diversity, and habitat associated with both natural and managed ecosystems. Indeed, much of the policy concern over global change is explicitly linked to such possible ecosystem impacts. Second, photosynthesis, deforestation, and other biospheric processes can affect the chemical composition of the atmosphere, hence contributing to global change. Human influences on ecosystem changes are increasingly a part of current policy debates.

Thus, ecological systems are intrinsically linked to global change through interwoven roles in biogeochemical dynamics, physical climate and the hydrologic cycle, and the actions of humans. However, the scientific uncertainties associated with the composition, distribution, and processes of ecosystems currently slow the formulation of sound, science-based policy options.

The current key questions in these research areas, their relevance to the evolution of public policy of global change, and the associated research of the FY 1991 U.S. Global Change Research Program include the following:

(1) ***What ecological systems are most sensitive to global change, and how can natural change in ecological systems be distinguished from change caused by other factors?***

The diverse climates of the Earth support an equally diverse array of species and ecosystems. Separating the intrinsic natural dynamic changes of ecosystems from those changes induced by human activities is a challenge that has plagued the ecological sciences and the public policy arena for some time.

The highest priority for determining the sensitivity, types, and causes of possible changes in ecosystems is the documentation of past, current, and future variation in ecosystem properties. Several ongoing monitoring programs and proposed research initiatives will address this need with regard to sensitive ecosystems (e.g., boreal forests, grasslands, and arid and high-elevation areas): DOE's research parks, USDA's forests and experiment stations, DOI's parks, wildernesses and other public lands, and NSF's Long-Term Ecological Research Sites. NASA's EOS satellite-based instruments will extend global observations of ecosystem type, state, and spatial extent. Furthermore, EPA, USDA, NSF, DOI, NOAA, and DOE will examine the ecosystem responses (e.g., alpine treeline change in the western U.S., shrub encroachment into rangeland, ecological succession, small-animal ranges and habitats, and marine ecosystems) to carbon dioxide increases, climatic stresses, and other disturbances.

(2) *What are the likely rates of change in ecological systems due to global change, and will natural and managed systems be able to adapt?*

Ecosystem change is controlled by the physiological processes of the individual species, as well as by the environments in which they exist. The photosynthetic response of plants to increased carbon dioxide concentrations is relatively fast and often accompanied by higher biological productivity and drought and salinity resistance. However, the full responses of complex ecosystems, such as forests and rangelands, to changes in the climate system and in the chemical composition of the atmosphere may take decades or longer.

Understanding the ecological response to rates of change and how well ecological systems can adapt to change is clearly linked to quantifying impacts for the formulation of policy options. This will require (i) knowledge of ecological responses to specific forcing agents (e.g., temperature stress, soil moisture, chemical exposure, ocean circulation, and ultraviolet radiation), (ii) research on the interactions between biotic and abiotic processes, and (iii) modeling of interactions, feedbacks, and ecological responses.

The proposed and ongoing research of several agencies will contribute to closing these knowledge gaps. EPA and DOI will develop correlations and models to investigate rates of change in forested and semi-arid ecosystems. USDA, DOE, NSF, and DOI will acquire data on physiological and ecosystem responses in seedling productivity; variation of plant growth due to carbon dioxide, temperature, and ultraviolet exposure; ecosystem changes in high-desert rangeland and coastal regions; successional change of vegetation across climate gradients; and response of managed forests to drought stress. Furthermore, DOE, DOI, USDA, NOAA, and NSF will investigate the responses of particularly sensitive species (e.g., arctic marine mammals, reef corals, commercial fish stock, grasses, grains, and endangered or limited-habitat species) to climatic and other stresses.

(3) *How do ecological systems themselves contribute to processes of global change?*

The biogeochemical and physical feedbacks from living systems strongly influence the fluxes and amounts of methane, nitrous oxide, carbon dioxide, and the reactive trace gases in the atmosphere, as well as albedo and water fluxes. Decisions regarding land-use policies require that these causative interactions be understood and that their feedbacks be represented correctly in global system models.

DOE, EPA, USDA, NSF, and DOI ongoing and new programs will address these needs through projects that determine the influence of soil biology, total biomass, land-cover type, and transpiration on biogenic gas fluxes and evapotranspiration in different vegetation types, and that characterize the interactions between climate, vegetation, and soils in diverse ecosystems.

Earth System History

Table 1 shows that the FY 1991 request for this element is $19.1 million, a $11.4 million or 148 percent increase over the FY 1990 level.

Geological and historical records document the natural variability of the physical environment, climate, and ecosystems from interannual to millennia time scales. These data reveal periods that were significantly colder and warmer than today, as well as past abrupt climate changes and subsequent environmental responses. Understanding this past behavior of the natural system is essential for detecting predicted human-caused perturbations against the background of normal variability and for providing data sets to test climate models. Confidence in model predictions of future change will be increased if the models can reproduce these past climates.

Uncertainties in the predictions of climate models is already a key factor in policy debates, as is whether a greenhouse "signal" can be found in the record of recent decades. In addition, past evidence of the impact of climate changes on ecosystems demonstrates the vulnerability or resilience of these systems to change.

The FY 1991 research efforts listed below reflect the Program's research priorities (see Figure 1) and involve the following policy-relevant questions:

(1) ***What are the natural ranges and rates of change in the climate and environmental systems?***

The paleoclimatic record can provide insight into the cause and effect of global changes. The history of atmospheric carbon dioxide and methane along with records of past climates can be reconstructed from ice core samples. Similarly, the temporal covariations in the terrestrial biosphere, the carbon cycle, and climate need to be reconstructed from fossils, ocean sediments, and the geological record.

To address these opportunities and needs, DOI and NSF will focus on developing new paleoclimate methods, reconstruct past abrupt climate transitions and past warm intervals on Earth, and emphasize studies in the sensitive arid (DOI) and polar (NSF and DOI) regions.

(2) ***How rapidly have ecosystems adapted to past abrupt transitions in climate?***

The long-term geologic record contains evidence for a number of minor- to large-scale, rapid changes that have had profound effects on Earth systems and hence offers the opportunity to observe the environmental effects (e.g., extinction and replacement of biota) of a large sudden perturbation.

While the general characteristics and timing of major abrupt changes throughout the geological record are known, the existing studies are generally incomplete and limited in scale and scope. Better understanding of their effects on Earth systems will require the integrating of records on regional to global scales for selected events.

The programs of USDA, DOI, and NSF will contribute studies that emphasize the effects on the biosphere. The ongoing paleoclimate programs of USDA focus on the impacts of fire severity and frequency on the life histories and distributions of biota. New initiatives will study the effects of climate change on arid regions (DOI), and the impact of abrupt climate changes on ecosystems (NSF).

(3) ***Do past warm intervals in Earth history provide appropriate scenarios to test model predictions of future global warming?***

The assessment of the regional predictions of general circulation models will benefit from a comparison to data showing how representative regions responded during past warm periods. Intervals of past warm climates are known, but most of the environmental reconstructions of those times are qualitative and the scope of the variables is not comprehensive, which is a limitation in assessing the reliability of the models.

The Program will focus on determining if regional responses to global warming are similar regardless of local conditions or causes of the warming. This goal will be addressed by existing paleoclimatic research projects, such as the Climate of the Holocene Mapping Project (COHMAP) (NSF and DOE) and the Pliocene Project (DOI), as well as by augmenting existing and supporting new interdisciplinary programs. NOAA will augment its study of integrated paleoclimate investigations and global model assessment for these warm-Earth scenarios.

Human Interactions

Table 1 shows that the FY 1991 request for this element is $15.0 million, a $10.2 million or 212 percent increase over the FY 1990 level.

A comprehensive picture of global change must include the relationship between biological, atmospheric, hydrologic, and terrestrial changes and the human activities that stimulate or mediate them. These relationships include both the cumulative effects of individual or group actions over long periods of time and the less-concentrated, but equally influential, effects of the actions of social and economic institutions. For example, greenhouse gas emissions are due to several social and economic factors, including growth of human population, energy consumption, agricultural and industrial practices, and regulations.

Without an understanding of human behavior and its consequences for the environment, models will be inadequate to explain, or to develop policies to deal with, global change phenomena. The following research efforts reflect the Program's research priorities (see Figure 1) and involve the following policy-relevant questions:

(1) *What kinds of empirical data are needed to measure and understand human interactions in global change?*

The study of human interactions is dependent on having time-series data on a wide variety of human activities and related phenomena, ranging from energy demands to food consumption patterns. The necessary first step is to establish baseline data on environmentally significant human activities that reflect the differing technological, economic, and cultural forces in various societies.

NSF is supporting the collection of baseline data in environmentally critical areas and will establish Long-Term Regional Research Sites. These will support research on methodological problems in creating data bases which span the range of human activities in various regions and societies and will also encompass historical data. DOI will develop data sets for research that addresses the human factors which influence supply and demand of water and land resources. USDA will organize the data necessary for studying the role of human behavior in natural and managed ecosystems, and in the extent and severity of fires. DOE will continue its data collection on fossil fuel utilization and carbon dioxide emissions.

(2) *How and why do human beings and human systems influence physical and biological systems?*

The development of an accurate predictive understanding of human influences on global change (and hence appropriate public policy responses) is dependent upon the availability of data bases that span time and space, characterizing the fundamental processes of change in human systems, and the interactions of these systems with the physical and biological processes. Therefore, a critical early step in understanding human interactions in global change is the support of process studies.

NSF will expand its Human Dimensions of Global Environmental Change Program to put additional emphasis on social processes such as the economic influences in deforestation and the effectiveness of legal and regulatory controls over water resources. NSF's Long-Term Regional Research Sites will be the focus of research on long-term patterns and processes of social, economic, and ecological change. DOI will support the development of methods to estimate: (i) tradeoffs among competing social, environmental, and economic goals, and (ii) the role of human choices on water supplies and in coastal erosion and inundation. USDA's research program will include the effect of fires on rural population distributions.

Solid Earth Processes

Table 1 shows that the FY 1991 request for this element is $80.9 million, a $23.5 million or 41 percent increase over the FY 1990 level.

Many solid Earth processes are directly involved in the life-sustaining elements of the regional and global environment. Melting of glaciers, especially polar ice sheets, would cause sea level to rise; large volcanic eruptions can cause climatic cooling for short periods of time; and methane released from permafrost and gas hydrates in response to climatic warming can change atmospheric composition. An improved understanding of solid Earth processes will allow for more effective long-term planning in those coastal regions most vulnerable to rising sea level and for the protection of human populations most apt to be endangered by volcanic eruptions and other catastrophic solid earth processes.

The FY 1991 research efforts listed below reflect the Program's research priorities (see Figure 1) and involve the following policy-relevant questions:

(1) ***How do different coastal regions respond geologically and ecologically to higher sea level, and how can the contributions from changes in climate (e.g., glacier melting and ocean warming) be differentiated from those due to tectonic processes?***

Sea level is predicted to rise as a consequence of global warming, but the absolute magnitude, rate, and timing of the sea level rise are uncertain. Elevated sea level could have serious consequences for coastal environments and human populations, and an improved predictive capability for sea level rise is required for the effective formulation of adaptation or mitigation strategies.

Understanding sea level changes and their consequences requires measurements of the absolute magnitude and rate of sea level rise; differentiation between the contributions of climatic change from those due to movements of the Earth's crust; and prediction of the geological and ecological response of different coastal environments.

Ongoing and new research programs that contribute to these areas include: studies of glaciation and deglaciation during periods of climatic change (NSF and DOI); *in situ* global sea level network (NOAA); satellite ocean altimetry (TOPEX: NASA); the NOAA, NSF, and NASA programs to use the space-based Global Positioning System (GPS), Satellite Laser Ranging (SLR), and Very Long Baseline Interferometry (VLBI) to measure sea level changes; studies of coastal erosion and inundation on the East Coast of the United States (DOI and NASA); Coastal Wetlands Change and Dynamics Program (DOI); and the application of new isotopic methods for dating of landforms, soils, and sediments (NSF).

(2) *What are the magnitude, geographic location, and frequency of volcanic eruptions and their effect on climate?*

Large volcanic eruptions emit gases, ash, and aerosols into the atmosphere that can cause significant short-term perturbations to the Earth's climate by changing the radiative budget. It is essential to quantify climate change induced both by volcanic eruptions and by increased abundances of greenhouse gases.

Understanding the impact of volcanic eruptions on the Earth's climate requires an improved understanding of the magnitude, frequency, and geographic location of subaerial and submarine volcanic events and the nature and amount of emitted material. Hydrothermal venting from the ocean floor is a major source of heat from the Earth's interior, and it influences the global carbon cycle.

Several ongoing and new programs contribute to this research effort including: studies of gas and ash emissions and degassing processes from U.S. volcanoes (DOI); satellite measurements of atmospheric volcanic aerosols and sulfur gases (Total Ozone Mapping Spectrometer, Earth Probes, and EOS: NASA); and studies of the fluxes of energy, gases, fluids, and particulates from submarine eruptions on the mid-ocean ridges (Ridge Interdisciplinary Global Experiment [RIDGE]: NSF, NOAA and DOI).

(3) *How do permafrost regions of the Northern Hemisphere respond to climate warming?*

An accelerated release of methane trapped in arctic permafrost and gas hydrates due to a climatic warming would alter the chemical composition of the atmosphere and further enhance the greenhouse effect. Ongoing and new research will contribute to this area through projects that study the dynamics of permafrost change (NSF) and by assessing whether there is a current climatic warming on a local, regional, or hemispheric scale by monitoring subsurface temperatures in arctic permafrost (DOI).

Solar Influences

Table 1 shows that the FY 1991 request for this element is $13.2 million, a $4.4 million or 50 percent increase over the FY 1990 level.

The sun influences two of the most important current policy-related phenomena: the depletion of ozone by chlorofluorocarbons and climate warming due to greenhouse gases. In both areas, the main scientific problem is one of separating the effects that are due to human influences from changes induced by natural forcing agents, such as the sun.

The FY 1991 research efforts listed below reflect the Program's research priorities (see Figure 1) and involve the following policy-relevant questions:

(1) ***What aspects of solar variability are influencing the stratospheric ozone layer?***

Since ozone is generated by the breakup of oxygen by solar UV radiation, observed ozone changes will depend, in part, on solar activity. Thus, the detection of human-caused ozone depletions requires that the solar component of ozone change be properly accounted for. This understanding requires long-term UV observations of adequate precision (±1%) over the solar cycle. The required observations will be provided by instruments on NASA's Upper Atmosphere Research Satellite (UARS) and EOS.

(2) ***What impact do other inputs, e.g., particles, have on the upper atmosphere and how are they coupled to other atmospheric regions?***

The physical properties of the upper atmosphere (e.g., temperature, composition, and density) are sensitive to human-influenced gases, such as carbon dioxide and methane, and to solar particles. Changes induced by these agents could be quite substantial and hence could affect satellite orbits and provide insight into potential sun–atmosphere couplings. NSF's Coupled Energetics and Dynamics of Atmospheric Regions (CEDAR) and Geospace Environment Modeling (GEM) programs will begin the establishment of data bases on solar inputs relevant to the global circulation and couplings.

(3) ***How does the sun's output vary and what is the impact on terrestrial climate?***

A key factor in establishing the Earth's radiation budget is the total solar radiation reaching the planet. This requires continuous measurements of the total solar radiation with very high long-term stability (0.1%). These observations will be provided by Active Cavity Radiometer Irradiance Monitors (ACRIM) on NASA's UARS and EOS.

Data Management

Table 1 shows that the FY 1991 request for data management is a $129.4 million, a $64.2 million or 98 percent increase over the FY 1990 level.

Data and information management will provide a bridge between global change observations and scientific understanding, and will be a key factor in the success of programs carried out within all seven interdisciplinary science elements. The traditional concepts and present practices of data management are inadequate for global change studies. The interdisciplinary, interagency, and international aspects of these studies, coupled with a long-term view, pose unprecedented challenges to the data management and research communities alike. Consequently, cooperation in seeking new approaches to archiving and management of data is essential.

Data management includes the means and mechanisms to describe, gather, transmit, validate, process, archive, and disseminate data. The initial thrust will be on data base development in the highest priority science elements and strengthening the infrastructure required to process, manage, and improve access to the great variety of ground- and space-based observations.

The key data management questions with policy implications include:

(1) ***How can the data handling and access capabilities be best organized and strengthened?***

Data management systems for global change must be able to accept and archive dissimilar types of data collected from different data collection systems , i.e., both ground- and space-based data by different organizations in different formats and on different media.

Interactions among CES agencies through the Interagency Working Group on Data Management for Global Change and with the science community have begun to facilitate improved access to data and data handling capabilities. A major problem facing scientists attempting to use global change data sets is that it is extremely difficult to find out who has what data and how good the data are. Using existing facilities, NASA, NOAA, NSF, DOE, and DOI will continue to develop and expand a Master Directory for Global Change Data by linking with a common architecture, directories, catalogs, and inventories of data in all global change science elements. Hundreds of global change data sets already have been documented and entered.

Studies have been initiated to develop archives with improved quality control, documentation, and ease of access to satellite data, including formation of the EOS Data and Information System (NASA, NOAA and DOI), and procedures are being developed for better distribution of digital data bases. Access to and assimilation of the DOD environmental data bases are being addressed. Bilateral agreements have been signed between NASA and NOAA and between NASA and

USGS for the development of data systems to manage satellite data. The exchange of satellite information between NASA, NOAA, European Space Agency (ESA), Canada, and Japan has been instituted. NASA and NOAA are gathering relevant foreign data to combine with U.S. data.

(2) ***How can the agencies build the data sets needed to facilitate early results from the Program?***

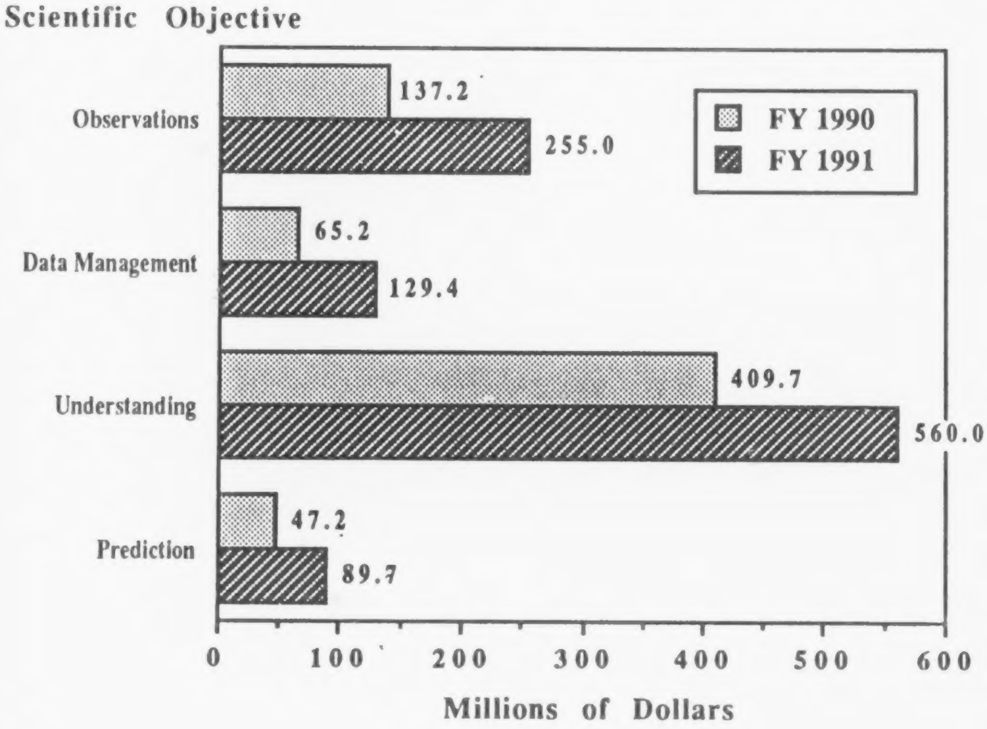
Long-term global measurements must routinely be supported by documentation regarding instrument calibrations, coverage, sampling, data editing, data reduction algorithms, including ancillary data, algorithm validation, assimilation or analysis procedures, and correlative measurements.

Many ongoing and new research programs contribute to the task of developing integrated global-scale satellite and *in situ* data sets that will support model development including the development of data bases in support of: biological responses to climate, abrupt climate change, anthropogenic forces in global change, long-term ecological research, studies of ecosystem stress, land-surface data, fire severity and occurrence, sea surface temperature fields, and regional ecosystem variables that are sensitive to global change. (All CES agencies are involved in one or more of these activities.) DOE will support a critical review of data for climate modeling, and NSF will support a geosystems data base activity that includes the development and quality control of model-generated data sets. On a priority basis, data sets are being extended into the past, both to document global change and to test and validate diagnostic and predictive models. NOAA and NSF data management elements provide resources for the development of historical and paleo data bases. DOE and DOI have similarly focused programs.

Budget by Scientific Objective

Figure 3 shows the FY 1990 enacted and FY 1991 proposed budgets for the U.S. Global Change Research Program by scientific objective: observations, data management, understanding, and prediction. These budgets reflect a balance between each of the scientific objectives, with a strong commitment to data management.

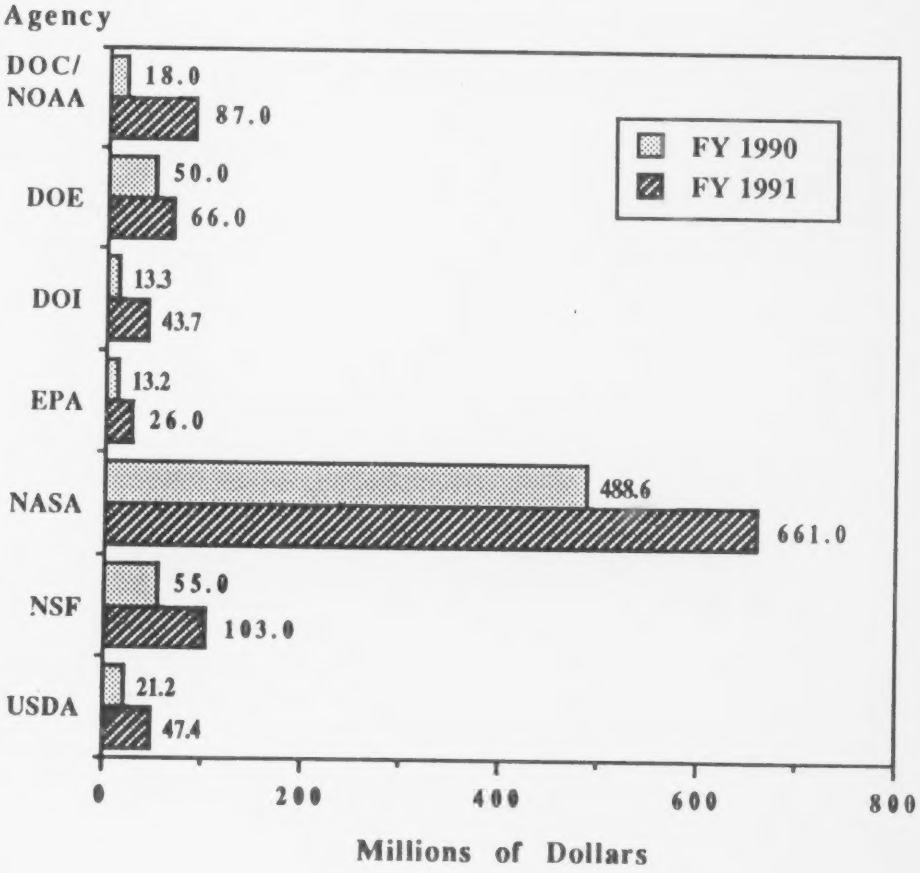
Figure 3
U.S. Global Change Research Program Budget
by Scientific Objective



Budget by Agency

Figure 4 shows the FY 199O enacted and FY 1991 proposed budgets for the U.S. Global Change Research Program by agency. The individual agency efforts build upon their respective scientific and technical strengths.

Figure 4
U.S. Global Change Research Program Budget by Agency



National Oceanic and Atmospheric Administration (NOAA). In FY 1991, NOAA has proposed an $87 million Climate and Global Change Program in support of the U.S. Global Change Research Program. This represents a $69 million or 383 percent increase above the FY 1990 level. The FY 1991 NOAA contribution involves enhancements to ongoing efforts in: operational *in situ* and satellite observation programs with an emphasis on oceanic and atmospheric dynamics (including sea level), circulation, and chemistry; focused research on ocean-atmosphere interactions, the global hydrological cycle, the role of oceanic circulation and biogeochemical dynamics in climate change, atmospheric trace gas/climate interactions, and the response of marine resources to climate change and related stresses; and programs to improve climate modeling, prediction, and information management capabilities.

Department of Energy (DOE). In FY 1991, DOE has proposed a $66 million budget for global change research, a $16 million or 32 percent increase above the FY 1990 level. The DOE maintains a research program directed at the impact of energy production and use on the global Earth system by focusing primarily on climate, atmosphere, ocean, and ecosystem responses. DOE will augment research on climate modeling; studies of carbon dioxide sources in the atmosphere, oceans, and land; impacts on vegetation and ecosystems; and research efforts to quantitatively describe the radiative balance and the cloud-climate feedback in the atmosphere. New initiatives focus on critical data needs for global change research and the climatic variables that may serve as indicators of global change; and on funding to provide education and training to the next generation of scientists.

Department of the Interior (DOI). In FY 1991, DOI has proposed a $43.7 million budget for global change research, a $30.4 million or 229 percent increase above the FY 1990 level. DOI efforts include studies of: paleoclimates; interaction and sensitivity of hydrologic, ecological, and landscape systems with climate; arid, polar, and coastal regions and systems; volcano-atmosphere interactions; methane hydrates; changing land surface characteristics; ocean heat fluxes; social, environmental, and economic consequences of global change including human activities, water resources, biological species variation, and land management; and carbon cycle variation studies; as well as archiving and distributing space- and land-based Earth science data.

Environmental Protection Agency (EPA). In FY 1991, EPA has proposed $26 million for global change research, an increase of $12.8 million or 97 percent above the FY 1990 level. EPA's research efforts are focused on evaluating the processes and quantifying the relative contributions of anthropogenic and biological sources of trace gases, quantifying and modeling the consequences of climate change on ecosystems and their subsequent feedback to the atmosphere, and the interaction of trace gases in the atmosphere. Special emphasis will be given to climate sensitive regions, e.g., tundra, wetlands and forests. EPA's research will help provide the process-level understanding and modeling capabilities to predict global change.

National Aeronautics and Space Administration (NASA). In FY 1991, NASA has proposed $661 million for global change research, an increase of $172.4 million or 35 percent above the FY 1990 level. NASA research efforts are primarily focused on space-based studies of the Earth as an integrated system. These activities include ongoing research and satellite programs (e.g., the Upper Atmosphere Research Satellite, Ocean Topography Experiment, etc.) that are important precursors to the FY 1991 initiatives: Earth Probes (a series of satellite measurements prior to EOS to monitor atmospheric ozone, ocean color, precipitation in the tropics, and ocean surface winds) and the Earth Observing System (EOS). EOS will provide an integrated, comprehensive monitoring and data management program of simultaneous measurements of key global change variables.

National Science Foundation (NSF). In FY 1991, NSF has proposed $103 million for global change research, an increase of $48 million or 87 percent above the FY 1990 level. NSF proposes to augment and initiate programs coordinated internationally to observe, understand, and model atmospheric, oceanic, terrestrial, and social processes and their coupled interactions. Studies include ocean circulation, ocean-atmosphere interactions, cloud-radiation interactions, global atmospheric chemistry, biogeochemical processes, land-sea interactions, past climate change, crustal and related processes impacting global change, ecosystems, solar processes, human dimensions of global change, data base research and development, and a multi-agency education initiative for global change.

United States Department of Agriculture (USDA). In FY 1991, USDA has proposed $47.4 million for global change research, an increase of $26.2 million or 124 percent above the FY 1990 level. USDA research efforts are focused on ground-based research programs studying agricultural, forest and range ecosystems as influenced by factors such as water balance, atmospheric deposition, plant responses to changes in atmospheric constituents, UV-B radiation and other global change variables. Some representative studies that will focus on agricultural effects on environmental variables will include mechanisms of methane generation and nitrous oxide release; soil properties including moisture, erosion, organic matter dynamics, nutrient fluxes, and microbes; relationship of global change to forest and range fires, insects, and plant pathogens; and agricultural management systems.

Budget by Federal Budget Function

Scientific, environmental, energy, and agricultural resources are vital to the health of our Nation. Table 3 shows the FY 1990 enacted and FY 1991 proposed budgets for the U.S. Global Change Research Program by Federal Budget Function. In FY 1991, significant increases above FY 1990 levels are proposed for each budget function. The U.S. Global Change Research Program must be viewed as a single integrated research effort with its success dependent upon cooperation and contributions from each of the individual agency programs.

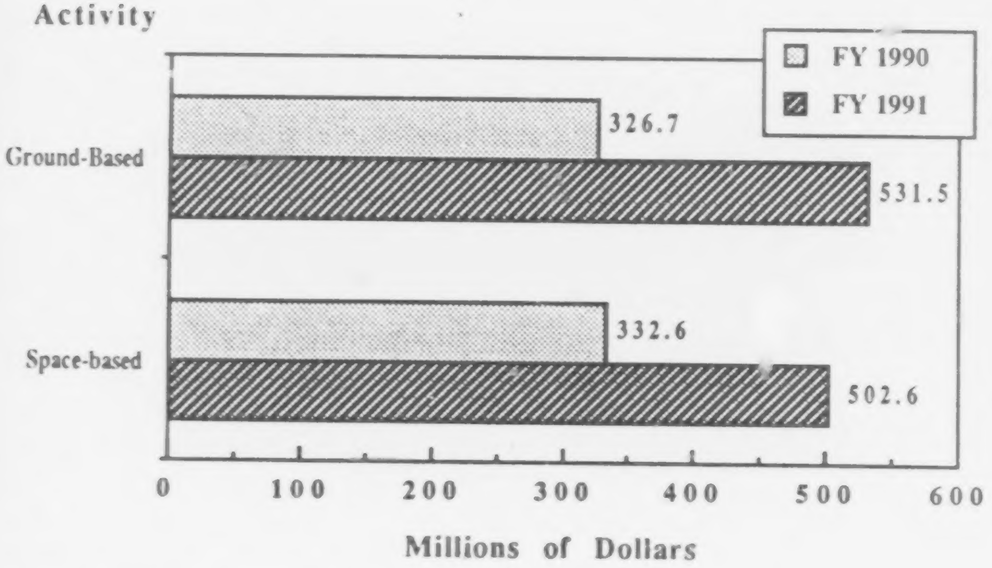
Table 3
FY 1990 - 1991 U.S. Global Change Research Program
by Budget Function
(Dollars in Millions)

Budget Function	Budget Function Number	1990	1991
TOTAL		659.3	1034.1
General Science, Space and Technology	250	543.6	764.0
NASA		488.6	661.0
NSF		55.0	103.0
Energy (DOE)	270	50.0	66.0
Natural Resources and Environment	300	44.5	156.7
DOI		13.3	43.7
EPA		13.2	26.0
DOC / NOAA		18.0	87.0
Agriculture (USDA)	350	21.2	47.4

Budget by Ground- and Space-Based Research

Figure 5 shows the FY 1990 enacted and FY 1991 proposed budgets for the U.S. Global Change Research Program by space- and ground-based research activities. Maintaining an appropriate balance between ground- and space-based research programs is essential for a successful U.S. Global Change Research Program. *In situ* and theoretical studies of physical, chemical, biological, and geological processes must be complemented by a comprehensive space-based program to provide the global observations of key environmental variables. The combination of ground- and space-based measurements is required given the temporal and spatial variability of the systems being studied, and the need to scale the processes occurring at the local level to the regional and global levels. The ground-based program is essential to interpret some of the global satellite observations (e.g., long-term trends), as well as to obtain scientific information not attainable from space (e.g., trace gas fluxes). Both types of program need to be strongly supported, and the FY 1991 budget reflects a reasonable balance.

Figure 5
U.S. Global Change Research Program Budget
by Ground- and Space-Based Programs



Ground-based: The FY 1991 request for the ground-based program is $531.5 million, a $204.8 million or 63 percent increase over the FY 1990 level. The budgets of NOAA, DOE, DOI, EPA, NASA, NSF, and USDA include support for a broad range of ground-based and modeling research activities. The activities range from small individual investigator research programs to participation in complex international scientific projects. The budgets would initiate multi-agency research thrusts in several critical areas including: the role of the oceans and terrestrial biosphere in trace gas fluxes; the exchange of energy between the oceans and atmosphere; the cycling of water throughout the Earth system; and expanded monitoring of responses to global change, such as sea level.

Space-based: The FY 1991 request for space-based programs is $502.6 million, a $170.0 million or 51 percent increase over the FY 1990 level. The NASA budget includes continued support for TOPEX and UARS, as well as the Earth Probes and EOS initiatives. The TOPEX, UARS, and Earth Probes missions will provide key global measurements, prior to the EOS era that starts in late 1997, including stratospheric composition; surface topography of the global oceans and sea surface wind velocity in order to advance the understanding of ocean circulation; rainfall in the tropics in order to determine the role of tropical precipitation in climate; and ocean color to improve the understanding of ocean productivity. EOS will provide an integrated, comprehensive monitoring program of simultaneous measurements of key global change variables, coupled with a comprehensive data and information system.

U.S. scientific agencies are playing a key role in a number of interdisciplinary international scientific programs involving the land, oceans, and atmosphere, and interactions between them, that require a combination of ground- and space-based measurements for successful implementation. These programs include: World Ocean Circulation Experiment; Tropical Ocean - Global Atmosphere; Global Ocean Flux Studies; Global Ocean Ecosytems Dynamics; Global Energy and Water Cycle Experiment; Global Tropospheric Chemistry Program; International Satellite Cloud Climatology Program; and International Satellite Land Surface Climatology Program.

The Carbon Cycle: An Example of Interdisciplinary Research

Modification of the global carbon cycle by human activities spans both science and policy concerns. This section of the report presents a case study of how the U.S. Global Change Research Program approaches a complex multidisciplinary research area like the carbon cycle.

Policy Needs

Emission of carbon dioxide from the combustion of fossil fuels and changes in land-use practices, and of methane from cattle, rice paddies, permafrost, natural wetlands, gas hydrates, and natural gas production are partly responsible for perturbation of the carbon cycle. Changes in the carbon cycle may affect regional and global climate, the chemistry of the atmosphere, the hydrologic cycle, and the productivity and functioning of ecosystems. Consequently, prudent environmental policy formulation will require a solid scientific understanding of how the carbon cycle varies naturally, how human activities change it, and how it might respond to future changes in environmental conditions.

Scientific Background

Atmospheric carbon dioxide is a radiatively active trace gas with concentrations 25 percent greater now than in the pre-industrial era (prior to 1850) and increasing at about 0.4 percent annually because of human activities. Annual anthropogenic emissions of carbon dioxide are currently about 5.5 billion metric tons from fossil fuel combustion, plus an additional 0.8 to 3.0 billion metric tons from tropical deforestation. Over the past century, fossil fuel use and cement manufacturing released about 200 billion metric tons of carbon into the atmosphere. In the same time period, land-use changes (primarily deforestation) may have released as much as an additional 115 billion metric tons of carbon. However, only 130 billion metric tons of these combined releases remain in the atmosphere. A critical question concerning the global carbon balance is, "What has happened to the remaining carbon dioxide and what will happen to it in the future?"

The natural fluxes of carbon dioxide into and out of the atmosphere from the oceans and terrestrial biosphere are an order of magnitude greater than the anthropogenic fluxes. The oceans, which contain about 50 times more carbon than does the atmosphere, are known to be an important long-term sink for carbon from the atmosphere. In addition, while terrestrial vegetation has always assimilated atmospheric carbon dioxide by photosynthesis, it recently has been suggested that vegetation and soils at northern mid-latitudes may be becoming more effective in sequestering carbon from the atmosphere because of either changes in land management (e.g., reforestation) or because the increasing atmospheric carbon dioxide concentrations may be stimulating plant productivity. These oceanic, terrestrial, biogeochemical, and ecological processes ultimately determine the fate of carbon dioxide from human activities. However, uncertainties in the knowledge of the magnitude of the oceanic and terrestrial sinks limit the accuracy of forecasts of the future fraction of "anthropogenic" carbon dioxide that will remain in the atmosphere.

Atmospheric methane is a radiatively and chemically active trace gas whose concentration is now a factor of two greater than it was in the pre-industrial era and is increasing at about 1 percent annually, presumably because of human activities. The atmospheric abundance of methane is controlled by emissions from oxygen-deficient sources such as natural wetlands, permafrost and gas hydrates, rice cultivation, biomass burning, cattle, natural gas venting, and removal by atmospheric chemical reactions.

Uncertainties in the knowledge of the magnitude of the individual sources and sinks of carbon dioxide and methane severely limit the accuracy of forecasts of their future atmospheric concentrations.

Required Understanding

Biological and physical processes control the uptake and release of carbon by the oceans, and ecosystem dynamics are equally important on land. Economic and human factors dictate the magnitude of fossil fuel emission and the intensity of land disturbance. The task of predicting future abundances of atmospheric carbon dioxide, methane, and other carbon-containing gases requires scientific information, spanning numerous scientific disciplines, including: the exchange of carbon dioxide between the oceans and the atmosphere; the exchange of carbon dioxide and total carbon between the shelves and open oceans, and between the surface waters, deep ocean and sediments; the exchange of gases between terrestrial ecosystems and the atmosphere; the storage and cycling of carbon within terrestrial ecosystems; the extent and ecological state of terrestrial and aquatic ecosystems; atmospheric distributions and transformations of gases; paleocarbon budgets; and the influence of human choices on the carbon cycle.

U. S. Global Change Research Program Approach

After evaluating the policy needs, scientific background, and required understanding, a responsive, multidisciplinary research effort was developed. The box on page 54 gives examples of specific U.S. Global Change Research Program activities related to the carbon cycle. Synthesis and integration of results obtained by investigators working within their numerous disciplines is a critical challenge guiding the U.S. Global Change Research Program. This diversity of research, data collection, and modeling activities is typical of global change research.

Examples of Carbon Cycle Research Activities in the FY 1991 U.S. Global Change Research Program

Climate and Hydrologic Systems

- *General Circulation Models (GCM).* Conduct carbon dioxide scenario experiments in GCMs using coupled atmosphere-ocean models. (DOE, NASA, NSF, and NOAA)

Biogeochemical Dynamics

- *Earth Probes: Satellite Ocean Color Imager and Scatterometer.* Determine ocean productivity and the wind stress at the ocean surface, which will help characterize the carbon dioxide flux across the air/sea interface. (NASA)

- *Ocean Carbon Studies.* Initiate a program of high-precision measurements of carbon dioxide and total carbon, investigate the cycling of carbon in the world's oceans, and determine the air-sea flux of carbon dioxide. (NSF, NOAA, and DOE)

- *Global Carbon Dioxide and Methane Trends.* Monitor the changing abundance of the radiatively active trace species at globally distributed sites. (NOAA, NSF, NASA, and DOE)

- *Terrestrial/Atmospheric Carbon Cycling.* Determine the fluxes of methane and non-methane hydrocarbons from terrestrial ecosystems and the atmospheric processes that establish their lifetime. (NASA, NSF, NOAA, DOE, EPA, and DOI)

Ecological Systems and Dynamics

- *Carbon Cycling in Ecosystems.* Study carbon cycling in terrestrial ecosystems and the processes controlling carbon dioxide fluxes from photosynthesis, respiration, and land-use changes. (DOE, EPA, DOI, USDA, and NSF)

- *Land-Surface Characterization.* Develop data bases for improved vegetation characterization, such as vegetation/ land-cover maps, and vegetation greenness indices. (DOI, NOAA, and NASA)

Earth System History

- *Paleo-Atmospheric Carbon Dioxide Abundances.* Carry out ice core studies of carbon dioxide concentrations and other associated variables. (DOE and NSF)

- *Geological History of the Carbon Cycle.* Reconstruct changes in the distribution of carbon isotopes in the Earth's systems. (NSF and DOI)

- *Modeling the Past Carbon Cycle.* Develop models of the long-term partitioning of carbon between the atmosphere, ocean, and terrestrial reservoirs. (DOI)

Human Interactions

- *Carbon Dioxide Emissions.* Develop second-generation carbon dioxide emission models. (DOE)

- *Carbon Dioxide and Standard of Living.* Examine the national differences in fossil fuel consumption and its relation to the standard of living. (NSF)

Solid Earth Processes

- *Volcanic Carbon Dioxide.* Assess long-term volcanic contributions of carbon dioxide to the oceans and atmosphere. (DOI, NSF, and NOAA)

- *Methane Emissions from Permafrost and Methane Hydrates.* Assess the volume and potential release of methane from permafrost and methane hydrates. (DOI and NSF)

Special Issues

The CES has addressed several issues that are important to the success of the U.S. Global Change Research Program. The sections below describe those issues and the approach that CES has taken.

Education

The science of global change is complex and inherently multidisciplinary. While unraveling answers to scientific questions undoubtedly will require new approaches and technology, another important concern is the development of the human resources and scientific talent to conduct multidisciplinary global change research.

To address this need NSF and DOE will initiate human resources programs in FY 1991 that will annually support several hundred postdoctoral appointments, graduate students, and undergraduate students as research participants, as well as several summer institutes on interdisciplinary global change research problems. The NSF program will be managed by representatives from each of the CES agencies. Training opportunities, both in the U.S. and abroad, will include: (i) support at the individual project level, (ii) training centered at major research centers or technology centers, and (iii) opportunities for students to pursue training at institutions of their choice. The DOE program will encourage basic training at universities offering interdisciplinary programs and operational experience in team research at national laboratories and other science and technology centers. In addition, one component of the NASA EOS program is for educational scholarships.

Emerging Disciplines

The U.S. Global Change Research Program presented here should not be viewed as a full exposition of the details of the program in the outyears. The program will evolve as new projects are developed in response to scientific developments and policy needs. Each of the U.S. scientific agencies has programs at various stages of planning, and furthermore, there are major scientific planning activities related to global change within U.S. (Committee on Global Change of the National Academy of Sciences) and international (e.g., the International Geosphere-Biosphere Programme [IGBP] of the International Council of Scientific Unions [ICSU], and the World Climate Research Programme [WCRP] of the World Meteorological Organization [WMO]) scientific communities that have not reached the point of submission to agencies for any formal consideration. Examples include work on paleontology, hydrology, experimental ecology, and human interactions.

International Dimension

The U.S. Global Change Research Program is founded on the premise that international cooperation and coordination are fundamental to the scientific planning and the implementation of the entire Program. Research programs like the IGBP and the WCRP are truly international in scope and in design. The complex scientific agenda and the infrastructure needed to address the programs outlined here require a careful assessment and integration of the Program's components with programs of other governments; intergovernmental bodies (e.g., U.N. bodies such as the IPCC); and international non-governmental science coordinating and facilitating mechanisms (e.g., ICSU).

There is no "international" budget item included in the U.S. Global Change Research Program because it is integral to each project element. A major CES coordinating effort has been initiated with ICSU and the international scientific community, the intergovernmental organizations, and CES-like bodies in other countries. During 1990, it is expected that an integrating infrastructure will begin to evolve; will be endorsed by the various participating agencies, organizations, and institutions; and will involve to some extent the private and industrial sector. Bilateral and multilateral research agreements and programs between the U.S. and other countries are an essential part of this international framework.

Appendix

FY1990-1991 Global Change Research Program by Project

Agency		Project	Program Status
DOC	NOAA	TOGA-Tropical Ocean-Global Atmosphere,. incl. COARE-Coupled Ocean Atmos. Response Expt.	Enhanced
DOC	NOAA	Ocean Dynamics&Circulation: Atlantic Variability	
DOC	NOAA	WOCE-World Ocean Circulation Experiment	
DCO	NOAA	Chemical Tracers & WOCE Hydrography	
DOC	NOAA	Global Hydrological Cycle/GEWEX	
DOC	NOAA	Upper Ocean/Marine Surface Observations	
DOC	NOAA	Stratospheric Monitoring	
DOC	NOAA	Global Sea Level	
DOC	NOAA	Ocean Carbon	
DOC	NOAA	Climate Data Assimilation System	
DOC	NOAA	Long-Term Data Mgmt Planning & Infrastructure	
DOC	NOAA	Climate Modeling & Analytical Centers	
DOC	NOAA	Climate Diagnostics & Database Development	
DOC	NOAA	Paleoclimate Diagnostic Studies	
DOC	NOAA	Marine Sulfur Emissions/Cloud Feedbacks	
DOC	NOAA	Trace Gases/Radiatively Important Trace Species	
DOC	NOAA	Operational Ocean Modeling	New
DOC	NOAA	Long-Term Observing System Planning	
DOC	NOAA	Measurement Technique Development & Testing	
DOC	NOAA	GESDM-Global Environ. Sciences Data Mgmt	
DOC	NOAA	Near-Term Forecasting Improvement	
DOC	NOAA	Marine Ecosystem Response	
DOC	NOAA	Model-Based Fluxes	
DOE	OHER	Core CO_2 Research	Existing
DOE	OHER	Effects	
DOE	OHER	Information/Coordination	
DOE	OHER	Human Interactions	
DOE	OHER	Oceans	
DOE	OHER	Quantitative Links	Enhanced
DOE	OHER	ARM-Atmospheric Radiation Measurements	
DOE	OHER	Data for Climate Modeling/Detection	New
DOE	OHER	Education	
DOI	USGS	Coastal Erosion & Inundation	Existing
DOI	USGS	Permafrost	Enhanced
DOI	USGS	Interaction of Climate & Hydrologic Systems	
DOI	USGS	Land Surface Data System	
DOI	USGS	Paleoclimates Research	
DOI	USGS	Climate Arid Regions	
DOI	USGS	Biogeochemistry of Greenhouse Gases	
DOI	FWS	Coastal Wetland Change & Dynamics	New
DOI	FWS	Monitoring Fish & Wildlife Impacts	
DOI	MMS	Ecosystem Stress	
DOI	MMS	Physical Oceanography	
DOI	NPS	Integrated Studies NPS Ecosystems	

DOI	NPS	Dynamics of Coastal Systems	New
DOI	PBA	MESEEC- Methodologies to Estimate Social, Economic, and Environmental Consequences	
DOI	PBA	TOCSEEG-Tradeoffs between Competing Social, Environmental & Economic Goals	
DOI	BLM	Ecological Change in Environmentally Stressed Ecosystems of the Western & Northern U.S.	
DOI	USGS	Biogeochemical Research	
DOI	USGS	Sensitivity Hydrologic Systems	
DOI	USGS	Land Characterization	
DOI	USGS	Volcano Emissions	
DOI	WBR	Regional Studies	
DOI	WBR	Sensitivity Hydrologic Systems	
EPA	ORD	Emissions Research	Existing
EPA	ORD	Stratospheric Ozone	
EPA	ORD	Ecological effects	Enhanced
EPA	ORD	Regional Climate	
EPA	ORD	Biofeedbacks	
EPA	ORD	Tropospheric Chemistry	
NASA	OSSA	Space- Based	
NASA	OSSA	UARS-Upper Atmosphere Research Satellite	Existing
NASA	OSSA	TOPEX-Ocean Topography Experiment	
NASA	OSSA	Payload & Instrument Development	
NASA	OSSA	Scatterometer	
NASA	OSSA	Operations & Data Analysis	Enhanced
NASA	OSSA	Earth Observing System (EOS) Platform	
NASA	OSSA	EOS-Earth Observing System	New
NASA	OSSA	Earth Probes	
NASA	OSSA	Ground-based	
NASA	OSSA	Solid Earth Science	Existing
NASA	OSSA	Interdisciplinary Research & Analysis	
NASA	OSSA	Suborbital Research Observations	
NASA	OSSA	Model & Data Hydrology/Circ./Physical Climate	Enhanced
NASA	OSSA	Model & Data Solid Earth/Ecological Systems/ Biogeochemical Dynamics	
NASA	OSSA	Hydrologic/Circulation/Physical Climate Processes	
NASA	OSSA	Upper Atmosphere Research Program	
NASA	OSSA	Laser Network	
NASA	OSSA	Ecosystem Dynamics & Biogeochemical Processes	
NSF	GEO	Stratospheric Ozone	Existing
NSF	GEO	Antarctic Ecosystems	
NSF	GEO	TOGA-Tropical Oceans-Global Atmosphere	Enhanced
NSF	GEO	GTCP-Global Tropospheric Chemistry Program	
NSF	BBS	HDGEC-Human Dimensions of Global Environmental Change	
NSF	GEO/BBS	LMER-Land-Margin Ecosystems Research	
NSF	GEO	RIDGE-Ridge Interdisciplinary Global Experiment	
NSF	GEO	Geodynamics	
NSF	GEO	ARCSS-Arctic Systems Science	
NSF	GEO	Geologic Record	
NSF	GEO	CEDAR-Coupling, Energetics, & Dynamics of Atmospheric Regions	

NSF	GEO	GOFS-Global Ocean Flux Study	Enhanced
NSF	GEO	WOCE-World Ocean Circulation Experiment	
NSF	BBS	Bioresponse to Climate	
NSF	GEO	GEWEX-Global Energy&Water Cycle Experiment	
NSF	GEO	GEM-Geospace Environment Modeling	New
NSF	CES/NSF	Education & Training Program	
NSF	GEO	Abrupt Climate Change	
NSF	GEO	GLOBEC-Global Ocean Ecosystems Dynamics	
NSF	GEO/BBS	Geosystems Databases	
NSF	GEO	CHP-Continental Hydrologic Processes	
USDA	ARS	Biological Response to UV-B	Existing
USDA	CSRS	Atmospheric Deposition	
USDA	CSRS	Stratospheric Ozone Depletion	Enhanced
USDA	FS	Water Yield, Erosion & Sedimentation	
USDA	FS	Wildlife/Domestic Species Interactions	
USDA	FS	Aquatic Ecosystems & Fisheries Habitat	
USDA	FS	Fire Severity	
USDA	FS	Energy, Water, Carbon & Nutrient Cycles	
USDA	FS	Microbes, Plant Pathogens & Insects	
USDA	FS	Species Life History	
USDA	ARS	Ecosystem Modeling	New
USDA	ARS	Biogeochemical Fluxes	
USDA	ARS	Ozone Effects	
USDA	CSRS	Methane & Trace Gases	
USDA	SCS	Pedosphere-Paleoecology	
USDA	SCS	Pedosphere-Processes	

Key to Program Status

▒	Existing Program
☐	Enhancement of Existing Program
▨	New Initiative

Agency Acronyms

DOE	OHER	Office of Health & Environmental Research
DOI	FWS	Fish & Wildlife Service
	MMS	Minerals Management Service
	NPS	National Park Service
	PBA	Policy & Budget Administration
	WBR	Bureau of Reclamation
	USGS	U.S. Geological Survey
EPA	ORD	Office of Research & Development
NASA	OSSA	Office of Space Science & Applications
NSF	GEO	Geosciences Directorate
	BBS	Biological, Behavioral & Social Sciences Directorate
USDA	ARS	Agriculture Research Service
	CSRS	Cooperative State Research Service
	FS	Forest Service
	SCS	Soil Conservation Service

COMMITTEE ON EARTH SCIENCES

Dr. **Bromley**. What CES has done, as you noted, is to organize and coordinate the activities in some seven Federal agencies. I look on this as a model of the way that the Federal Coordinating Council should work in many areas. During the coming year I would like to see us address such areas as biotechnology, information technology, education and training, materials science, and technology, and similar crosscutting areas that are of great importance to our Nation in terms of economic competitiveness and national security, but that don't fit neatly into any single agency or science.

As you have already noted, Madam Chair, as a result of the activities of this committee, we were able to take forward to OMB, and then to the President, a coordinated program for the entire U.S. research activity, and because it had been peer reviewed, and adjusted within these various agencies, OMB was able to treat it essentially as a package. You see in the fiscal year 1991 budget that the President was able to come forward with a very substantial recommended increase; this is concrete evidence of his interest, and his evaluation of the importance of this area.

We have a whole set of priorities that have been developed during these CES studies. It has been a difficult task to develop those priorities, and the question is, Which data are most important, in terms of our being prepared—as you quite correctly noted, Madam Chair—to be prepared by the time we get to the Second World Climate Convention later this year, to be able to address the questions of stabilization of greenhouse gas emissions, and possible reductions of these emissions.

We were not in a position at Noordwijk to address those questions, because we simply did not have adequate input on the economic side. It is the President's conviction, and one that I share, that our policies must be based on the best science and best economics that we can get within a reasonable time scale, recognizing that we will never know everything that we might like to know about any of these subjects.

I would like to touch very quickly on a few of the priority areas of the science, and then turn to the policy questions relating to global warming.

GENERAL CIRCULATION MODELS

As you know, the way in which much of the science has been developed centers on the so-called general circulation models [GCM]. These are large mathematical models of how the Earth responds to radiation coming in from the Sun, and to possible changes in our atmosphere.

The problem with these models is, first, that the typical grid size is at least 100 miles, and so they average out the effect of mountains, and phenomena like the gulf stream and rivers, and so there are gross uncertainties on anything less than global scale.

The models do not include clouds or the interaction between the atmosphere and the oceans in any but the most unsophisticated way, and this too leads to uncertainties.

The range of predictions, if we were to double the amount of carbon dioxide in the atmosphere—which would happen if we did nothing, sometime in the midst of the next century—fall in a range from about 2 to 5 degrees Centigrade. Recent work has been tending to push that prediction down to the lower end of the band; this is particularly true of some of the most recent work.

You might well say, why don't we simply make the models better; and there are many reasons why we are unable to do so. First of all, we don't have adequate data sensing to support a finer grid, and second, if we were to modify the models so that the grid was 50 miles rather than something over 100, it would require an increase in costs and in computer power by a factor of 500.

We don't have, at the moment, any computers of such power, although they are on the horizon, and we don't have this level of funding. If we had the funding I am not sure that is where we would want to put it on a priority basis.

Clouds clearly represent a problem, because we have not yet understood how to treat them properly. Oceans are a major problem, because the upper three meters of the ocean contain as much heat as does the entire atmosphere. The ocean also contains 50 times more carbon than does the atmosphere. Minor changes at the interface between the ocean and the atmosphere can make major changes in what is happening in the atmosphere, and we now have records from the polar ice cores—a technique pioneered by our Soviet colleagues—where we can go backward in time and measure not only the carbon dioxide content of the atmosphere, but the temperature, and these track in remarkable fashion over the past several hundred thousand years.

We have to understand these particular interactions much better than we do now. One of the things, moreover, that bears mentioning is the fact that there is a tremendous desire on everyone's part to improve these models because—among other things—they will give us a guide as to what is most important for us to measure.

FORECASTING POSSIBILITIES

But even more important, let me just mention, from this CES document, what I think is a rather remarkable expectation. The Committee on Earth Science notes that the research that is already underway—what we are doing right now—will lead within the next 3 to 5 years, to seasonal forecasting that will tell us something about our weather over 30- to 60-day periods. That is in the next 3 to 5 years.

Within the next 10 years, they assert that we are going to be able to make at least reasonably good qualitative statements about interannual projections; what the next year is going to be like, in terms of gross weather and climate behavior.

And within perhaps a 10- to 20-year period, they anticipate that we are going to be able to say something useful about interdecadal projections; namely, what is going to happen 10 years from now. This material is in the CES document.

If we think of the importance to agriculture, as a single example, of knowing what the weather is going to be like a year in advance, or several years in advance, and think of what that would mean to people in monsoon areas, in the tropical areas of the world, then the enormous leverage becomes clear.

In many of these activities, we are relying on data that have been accumulated over the years from weather stations, and from weather bureaus, but we can bring to this whole venture something new that I know, Madam Chair, you are very much interested in; that is the new resource of being able to look down on our planet from space.

MISSION TO PLANET EARTH

Mission to Planet Earth is a very important development in my view. Part of that mission is the Earth Observing System [EOS], and that will, for the first time, allow us to look down at a particular point on the Earth simultaneously with 14 to 15 independent instruments.

The problem in the past has been that we look with one instrument in one satellite, and then later come over with another satellite, and we don't know what's happened on the ground in between—clouds, rainstorms, you name it.

With EOS we will get at least 15 shots at one point simultaneously. This will be crucially important to what we can do in areas that at the moment are limited only by our imagination.

It is going to take us some time to get the EOS platforms up there, and in the meantime, NASA has a coherent plan of using expendable launch vehicles to put up probes that will allow us isolated measurements that will make sure that when the EOS goes up, we are doing just the right thing; and in the meantime, these probes give us information of tremendous value in its own right.

Not only do we have a coherent program underway, but we have asked the National Academy of Sciences to take another look at this whole area, just to make sure that in working from where we are now to where we will be when we have the Earth observing satellites in place, we really will have used the funding that you and your colleagues, Madam Chairman, can make available to this program in the most effective and efficient way.

This is a responsibility that my office in particular shares, and working closely with OMB. Over this past year we have worked out, as I mentioned to you before, a new cooperative relationship between our two offices, so that we will be involved throughout the entire development of next year's budget right from the beginning, in all of the levels of our two offices. Science and technology will be phased into the deliberations from the very beginning.

NEED FOR IMPROVED EDUCATION

You, Madam Chair, have emphasized, and been a strong champion in the Congress, for what is really one of the very important components of this activity, and that is education. We do face a very real shortage of the kind of trained personnel that are going to be required to move this whole program forward. This is only part of the huge educational problem that we face as a nation.

There are two aspects to it. One is the development of literacy among the general public, so that they at least understand the broad issues involved, even if they may not be able, themselves, to participate in the detailed resolution of these issues.

The second is the production of the trained professionals—not only the Ph.D's, but also the technicians, and in fact, the technicians, I feel, are one of the most important groups, because we have ignored their importance. I feel very strongly about education and look forward to working with you and your colleagues in the Senate to make sure that we take effective action.

POLICY APPARATUS

Let me then, Madam Chairman, turn to the policymaking apparatus, because that has come under much discussion. The question really is, How do we come up now with the kind of policy that will adequately represent U.S. interests in the international forum where these matters will be discussed.

I want to tell you first about some of the steps that we have already taken. We agree in this administration that global change is a very serious problem that has to be treated seriously, and, moreover, that it is an international problem that is only going to be resolved by international solutions and cooperation.

We have, first, committed—ahead of the requirements of the Montreal Protocol—to end the production and use of CFC's before the year 2000. That in itself represents 25 percent of our greenhouse gas emissions, and we are committed to phasing it out.

We are also taking a number of steps to cut back on our production of carbon dioxide. Carbon dioxide, of course, is the signature of the combustion of fossil fuels, and the making of portland cement, and these are our major targets.

Fifty-seven percent of our greenhouse emissions come from these two sources, and we are already doing several things about them. The Clean Air Act is being reauthorized, and new efficiency standards are being applied; there are new lighting standards; and where I feel we have the greatest opportunity to make progress on the short term, through aggressive energy conservation—and an aggressive increase in the efficiency of our use of electricity, in lighting and in all sorts of areas.

I talked this past Saturday with David Packard of Hewlett-Packard, who emphasized that if we really put our minds to it, we could substantially increase the efficiency of even something with which we are as familiar with as our electric motors. We have come to think of them as being, at the very peak of efficiency, but there remains still a real opportunity to make improvements. There is a very real opportunity for us to make changes toward energy conservation in our industrial processes. Because we, among all the developed nations, are the only ones that developed these processes without phasing into our calculations what energy would cost. We simply assumed that we would have it as required, and that it would be cheap.

If we take as a single example; we get our aluminum via a fluoride process, and it is one of the most energy intense that we have. Had we instead used a chloride process—as we would have had we considered the energy costs—we would save one-third of the energy.

We don't make such changes immediately, simply because of the enormous capital investment involved, but that is illustrative, Madam Chair, of the sort of savings that we still have accessible to us in the industrial sector.

I am working with Admiral Watkins, and the Department of Energy, and we are cochairing a meeting tomorrow, on energy and science, working toward the completion of the new DOE national energy policy, which has been focused very strongly on energy conservation in all of its aspects, and on the development of alternative energy sources that do not produce carbon dioxide.

DOMESTIC POLICY COUNCIL WORKING GROUP

President Bush recognized last fall that it was essential that we speak with one voice in this country to the extent that we could, and to that end he asked me to chair the Working Group of the Domestic Policy Council, and charged us with developing U.S. policy on all issues relating to global change.

The members of that Working Group are the Cabinet members from all of the agencies that play any role in responding to environmental questions; we have now been in action for a number of months, and I believe that we are making progress.

When we began, Madam Chair, three things became very clear to us. First of all, we have an enormous untapped resource in this country that no one had talked to previously, and that is the private sector—industries that have been involved in these questions for decades.

We asked the Department of the Interior to coordinate our collection of data and expertise from the industrial sector, and second, we asked the Council of Economic Advisors to undertake an extensive modeling of the economic consequences of various scenarios that the science of global change suggested.

Third, because in the past we have signed international agreements that in retrospect were not totally in the best interests of the United States, we asked the Justice and State Departments jointly to reexamine our international agreements, and come up with a framework so that when we start negotiating, as we will—the President has committed us to negotiating a framework convention on global warming—we will know what things are most important to us as a nation, in terms of our economy, in terms of maintaining jobs, and in terms of all the impacts that such decisions could have.

In addition to this, I must tell you that last fall, those of us who went to the Noordwijk Ministerial Conference on global change representing the United States were convinced that a very large number of the countries who were prepared to sign up for a 20-percent reduction in carbon dioxide emissions by the year 2000 had no idea how they would accomplish this or what it would cost.

With that background, and to make sure that we understood as much as we could about it, we focused on the science/technology interface. To to that end the President noted in Malta, and on Monday of this week announced to the IPCC meeting, that this spring he would host a White House conference on scientific and economic research related to global change.

It will bring senior scientists, economists, and environmentalists, from all of the participating countries, and our goals here are those of getting better understanding of the techniques, both in science and economics, as well as the data we need to really understand these questions.

We want to sensitize the scientists and the economists to what one another are doing and what the important issues are. There is no point in our spending a lot of money to measure some data that really don't have much influence on the economic situation.

Senator MIKULSKI. Dr. Bromley, I want to be sure that I don't lose any Senators, in terms of questioning.

Dr. BROMLEY. Should I speed it up?

Senator MIKULSKI. If you could speed it up, or get to the highlights. It has been extremely informative so far, and some of my questions have been answered through your testimony, but I think if——

Dr. BROMLEY. Well, let me take just a few more moments.

Senator MIKULSKI. All right.

COUNCIL PULLED TOGETHER

Dr. BROMLEY. You mentioned that the President was going to pull together a Council of Advisors on Science and Technology [PCAST]. I am happy to be able to tell you that that Council has now been pulled together, and we met with the President for 3 hours at Camp David last Saturday.

I am the Chairman of the Council, and this first PCAST meeting has demonstrated not only the President's firm interest in working with the Council, but also the fact that the council is going to be of great help to us in bringing private sector input into the highest levels of Government.

Senator MIKULSKI. That's great.

Dr. BROMLEY. We are really looking forward to this PCAST interaction. Obviously, too, the fact that we had a plenary session of the Intergovernmental Panel on Climate Change [IPCC] here earlier this week is a demonstration of our continuing interests in the Bush administration in working within that framework to develop a firm international working agreement on how we can all work together to respond to the global change, and global warming, in particular.

With that, Madam Chair, let me simply terminate my comments; I would be happy to respond to any questions you may have.

Senator MIKULSKI. Thank you very much, Dr. Bromley, for a very comprehensive testimony. The entire statement of yours will be included in the record.

[The statement follows:]

STATEMENT OF DR. ALLAN BROMLEY

Thank you for inviting me to speak before you today on the subject of global warming. As this committee well knows, human beings have embarked on an enormous, unplanned planetary experiment that poses unprecedented challenges to our scientific understanding and our societal foresight The greenhouse effect is nothing new. Without carbon dioxide and water vapor in the atmosphere, which warm the earth by keeping infrared energy from escaping into space, the oceans would have frozen early in the earth's history and our planet would have remained lifeless. But since the beginning of the Industrial Revolution, human beings have significantly altered the composition of the atmosphere by burning fossil fuels, cutting down forests, greatly expanding agriculture, and producing industrial chemicals such as chlorofluorocarbons (CFC's). The release of manmade emissions into the atmosphere constitutes the single largest impact—by a substantial margin—that human beings have had on this planet.

Let me put this impact into perspective. On average, every human being on the planet accounts for the release of over a ton of carbon in the form of carbon dioxide into the atmosphere each year. Because of the United States' extensive use of fossil fuels, each American, on average, is responsible for the release of five tons of atmospheric carbon annually. Over the past two centuries, the amount of carbon dioxide in the atmosphere has risen 25 percent. The level of atmospheric methane, a potent greenhouse gas generated by agricultural and industrial practices, has more than doubled.

Scientists have predicted since the end of the nineteenth century that increases in atmospheric carbon dioxide would increase the temperature of the planet. However, a sequence of unusually hot years during the 1980s, including six of the ten hottest years on record, have helped to propel this issue toward the top of national and international agendas. In fact, warming seems to have begun slowly around 1880 and was thought indisputable by the late 1930s. However, between 1940 and the mid-1970s, global mean temperatures tended to decline, with another warming trend taking hold during the 1980s.

Scientists continue to struggle with understanding this nonlinear behavior. Our inability to separate human impact from natural variability and the uncertainties surrounding temperature records compound the problem. Nevertheless, few scientists would argue with the contention that if we continue to load the atmosphere with greenhouse gases, we will eventually experience significant warming.

Issues of global change are very important to me and to the President. Many people have the impression that the Bush Administration is doing less than other countries about global warming and other major environmental problems. That impression is entirely mistaken. If we measure progress in terms of concrete actions, we find that the United States is doing more than any other country to understand and address these problems.

A crucial factor in the actions we take has to be our understanding of the earth as a system and the human role in that system. It is imperative that the Bush Administration, in cooperation with the Congress, develop a well-designed program for research into both the earth system and the economic and policy aspects of potential responses. Using the results of this program, it will be possible to develop a rational global change policy based on the best available scientific and economic understanding. I look forward to working with you and your colleagues in Congress to accomplish these tasks.

RESEARCH ON GLOBAL CHANGE AND THE COMMITTEE ON EARTH SCIENCES

The Office of Science and Technology Policy is charged with reviewing and coordinating federal R&D that cuts across the missions of more than one federal agency and with providing advice to the President on issues of science and technology policy that affect national and international policy. In light of these responsibilities, global change is an archetypal science policy issue. Research on global change is being supported by a number of federal agencies, and global warming itself has assumed a prominent political visibility, as demonstrated by the President's addressing the Intergovernmental Panel on Climate Change earlier this week. OSTP will continue to devote substantial effort to global change and other important environmental issues.

OSTP's coordinating function in global change research has been carried out largely through the Committee on Earth Sciences (CES), which is one of the committees under the Federal Coordinating Council on Science, Engineering, and Technology (FCCSET), of which I am chairman. The CES has two subcommittees that deal with global change, the Working Group on Global Change, chaired by Robert Corell of the National Science Foundation, and a new Working Group on Adaptation and Mitigation Technologies, headed by John Knauss of the National Oceanic and Atmospheric Administration.

I would like to submit for the record a copy of the document "Our Changing Planet: The Fiscal Year 1991 U.S. Global Change Research Program," which was produced by the CES Working Group on Global Change to support the President's fiscal year 1991 budget request. This document follows two previous CES working group publications: "Our Changing Planet: The Fiscal Year 1990 Research Plan," which was released last summer, and "Our Changing Planet: A U.S. Strategy for Global Change Research," which accompanied the fiscal year 1990 budget submission.

The CES has organized the efforts of the federal agencies conducting research on global change into the U.S. Global Change Research Program (USGCRP). The goal of the program is to reduce key scientific uncertainties and to develop more reliable scientific predictions upon which sound policy strategies and responses can be based.

Because of the program's importance, the President proposed in his FY 1991 budget that funding for the program be increased to $1.03 billion, a 57 percent increase over fiscal year 1990. The proposed funding would significantly expand research, data gathering, and modeling activities through a carefully balanced mix of ground-based and space-based research. The emphasis given to the program in the budget testifies to the President's concern about this important environmental problem.

As part of the USGCRP, the CES has developed a set of priorities in the broad field of global change. Though the development of these priorities was a difficult task, they are an effective way to communicate a complicated and interdisciplinary program to participants and observers. The priorities are organized into seven categories: (1) climate and hydrologic systems, (2) biogeochemical dynamics, (3) ecological systems and dynamics, (4) earth system history, (5) human interactions, (6) solid earth processes, and (7) solar influences. The CES expects to update the research plan annually and to change priorities as research results are obtained and as non-federal groups provide input into the research process.

There are, of course, many questions that need to be answered before we understand the earth system and are better able to predict future changes. Some of the most interesting and important science questions concern the reliability of general circulation models, the earth's climatic history, the role of clouds, oceanic influences on the atmosphere and climate, the hydrologic cycle, and changes in ecosystems.

CLIMATE MODELING

The most common way to predict future climate is with general circulation models (GCM's). These models, which typically run on supercomputers to cope with the enormous computational requirements of characterizing the earth's climate, treat the atmosphere as a grid of points that interact with each other according to basic thermodynamic and kinetic laws. Unfortunately, these models provide only a relatively broad-brush representation of the earth as an integrated system. For instance, the horizontal distance between grid points is typically greater than 100 miles. Important influences on climate, such as the detailed effects of clouds, mountains, vegetation or unique factors like the Gulf Stream, may be emitted or significantly muted in current GCM's because of computational limits or a lack of understanding of the fundamental processes involved.

The consensus of state-of-the-art GCM's over the past few years has been that a doubling of carbon dioxide from preindustrial levels, which is expected to occur sometime during the next century, will raise mean global temperatures by 2 to 5 degrees centigrade. Recent results, taking into account more accurate representations of clouds and other climatic influences, have tended to lower the more extreme estimates.

One major problem with current GCM's is their inability to predict climatic change on a regional scale. For example, GCM's do not now agree on the effects of increasing carbon dioxide on soil moisture in agriculturally important areas of the world. Improving such predictions will require both improved models and more powerful computers.

PAST CLIMATE HISTORY

An important source of information in addition to GCM's is the earth itself. The earth's climate has varied considerably in the past. At the height of the last Ice Age 18,000 years ago, a sheet of ice over a mile thick covered much of the northern United States, and sea level was about 100 meters lower. At other times, the global mean temperature was substantially higher than it is today.

The geological record contains important information on past climates and their influence on ecosystems, hydrologic conditions, and landscapes. Tree rings, ice cores, fossils, geomorphic features, and sediment characteristics can provide valuable insights into the conditions we might expect if temperatures rise. These climatic histories can also be used to test and validate the predictions of GCM's.

CLOUDS

The effects of clouds and water vapor on global temperatures are just as important as the effects of carbon dioxide and other greenhouse gases emitted through human activities. Moreover, recent investigations confirm that the treatment of clouds in current GCM's can significantly alter the magnitude of a projected warming. For example, when British modelers recently changed their model's treatment of clouds, the model's projections of global warming due to a doubling of carbon dioxide dropped from 5.2 degrees centigrade to 2.7 degrees centigrade. While these modelers do not claim that the new approach is a better representation of reality, their results show that changing a single parameter, like clouds, can dramatically alter the outcome of current model projections.

A change of a few percent in cloud cover could either greatly exacerbate or substantially counteract the potential warming due to the emission of anthropogenic greenhouse gases. We are beginning to understand the net radiative properties of some kinds of clouds, but we need to know more about both the current global distribution of the different kinds of clouds as well as future changes in the mix of clouds.

OCEANS

Oceans play a major role both in transporting and absorbing heat and in providing a sink for many greenhouse gases. Because the heat content of the upper 3 meters of the ocean is equal to that of the entire atmosphere, it is clear that the oceans will be involved in climate change in an important way. For example, research on the El Nino phenomenon indicates that this irregular, aperiodic oscillation in global climate is centrally tied to the exchange of heat between the ocean and the atmosphere in the tropical Pacific. Similarly, evidence from the geochemical record suggests that a brief return to Ice Age conditions some 10,000 years ago was linked to a major change in the circulation of the North Atlantic. Thus, we can expect the evolution of climate change in the atmosphere to be strongly influenced by the capacity of the ocean to absorb, store, transport, and release heat.

The oceans also play a major role in influencing levels of carbon dioxide in the atmosphere. Only about half of the carbon dioxide that has been released by human activities now remains in the atmosphere. Much of the rest is believed to have been dissolved in the oceans, which contain about 50 times as much carbon as does the atmosphere. Scientists are still unsure how this exchange of carbon between the oceans and atmosphere takes place and whether current absorption patterns will continue.

HYDROLOGY AND GLACIATION

The water cycle is important for at least two reasons. First, changes in the phase of water, for instance from liquid to gas, are a major mechanism of heat exchange and transport. Second, temperature changes are not the only area of concern regarding future environmental changes. Soil moisture, water availability, precipitation patterns, glaciation, sea level changes, and storm intensity are also important.

GCM's generally predict increases in global precipitation, but they are not able to specify much about changes in precipitation events, such as more storms, storms of longer duration, or greater rainfall intensity. A second family of models now receiving increased use are mesoscale models, which operate over smaller areas with a higher resolution than GCM's. The challenge is to find the appropriate means to translate from the smaller scale to the scale of a GCM.

A potentially very serious impact of global warming is an increase in sea level, which would inundate coastal areas and contaminate freshwater supplies. However, recent studies indicate that global warming will not necessarily lead to a rise in sea level, even though water expands as it warms and the leading edges of glaciers are likely to retreat. There is likely to be more precipitation as the world warms, some of which will fall in the form of snow on ice and glaciers. Studies of such mechanisms have led to a recent revision of a projected sea level rise under doubled levels of carbon dioxide, from about three feet to a foot with a margin of error of 12 to 18 inches on either side.

ECOLOGY

The natural ecosystem is remarkably robust and adaptable. Nature fills seemingly every available niche with organisms that compete with each other and that mutually support each other. Given a changed environment due to human influences, nature would continue to populate those areas that experienced changed climates. What scientist do not know is how much and what kind of change in the ecology of an area will accompany a given climate change. Most changes will occur at the edges of ecosystems, where thermal and water stress and species competition have the greatest effect. How fast can ecological systems respond? What negative side effects can we anticipate?

An additional problem is the lack of understanding about how ecological systems contribute to global change. Exactly what effect does deforestation of a particular forest type have on global fluxes of greenhouse gases, for example, or on the earth's reflectivity? Will global change result in an increased frequency of fires, with concomitant releases of carbon dioxide, methane, and nitrous oxide?

SPACE-BASED GLOBAL CHANGE RESEARCH

To complement ground-based research, the Global Change Research Program includes research focused on space-based monitoring. The space-based research is particularly important because it is in many cases the only way to derive a global balance for important earth processes.

NASA's Mission to Planet Earth is a major part of the Global Change Research Program. This effort involves several ongoing satellite and research programs and three new initiatives: the Earth Observing System (EOS), Earth probes, and attached payloads on Space Station Freedom. EOS is a series of space-based instruments and platforms, developed by the United States, several European countries, and Japan, that will help us improve our understanding of Earth processes and global change. It will be our first opportunity to collect data simultaneously on a multitude of different features of the planet's environment. The fiscal year 1991 budget proposes the development of two series of EOS platforms; the first platform is planned for launch in 1998. The amounts of data that these instruments will capture and transmit is staggering. A comprehensive data management system will be developed as part of the Global Change Research Program.

EDUCATION

Meeting the challenges of the Global Change Research Program will require more scientists with expertise in the earth science disciplines. In particular, scientists will need the background to conduct multidisciplinary global change research. The National Science Foundation and the Department of Energy have proposed new education programs as part of the Global Change Research Program. The NSF program will include training opportunities at the individual project level, at major research centers or technology centers, and for students at the institution of their choice. The DOE program will encourage basic training at universities offering interdisciplinary programs. Most agencies also include fellowships as part of their research programs. The combined programs will annually support several hundred postdoctoral appointments, graduate students, and undergraduate students as research participants. Several summer institutes on interdisciplinary global change research problems will also be supported.

WORKING GROUP ON ADAPTATION AND MITIGATION TECHNOLOGIES

A week ago, John Knauss chaired the first meeting of the CES Working Group on Adaptation and Mitigation Technologies. This group is focusing on scientific and technological research aimed at: reducing future growth in emissions of greenhouse gases and increasing sinks for these gases; modifying current technology and practices to adapt to changing climate; and providing the basis for economic quantification of the impacts of proposed response strategies.

Among the topics the group will assess and consider are: the knowledge of current and likely future emissions of greenhouse gases; research now in progress, including the cost and feasibility of various response options; and the transfer of technology to developing countries.

POLICYMAKING APPARATUS

Before describing the entities within the Executive Branch that are helping to develop and implement the Administration's policies on global change, I would like to touch upon the steps that the Administration has already taken that have the effect of reducing the emission of greenhouse gases into the atmosphere.

First, the United States is committed to phasing out by the year 2000 the production of all ozone-destroying chlorofluorocarbons as long as substitutes are available, a commitment that exceeds the provisions of the Montreal Accord. CFC's presently account for a significant portion of our total greenhouse gas emissions, so reducing CFC releases to protect the ozone layer will also reduce potential impacts on global climate.

The United States is also taking a number of steps to improve energy conservation, which is the most immediate means of reducing the emissions of greenhouse gases because the majority of U.S. greenhouse emissions come from the combustion of fossil fuels. The Clean Air Act is being reauthorized and new appliance efficiency standards have recently been released by the Department of Energy. The Department of Energy is also conducting a thorough review and revision of our National Energy Policy, which will emphasize energy conservation and the development of alternate energy sources that do not emit greenhouse gases.

We are also working, through diplomatic channels with our colleagues in other countries, to develop programs that will save tropical forests. Besides being a major sink for carbon dioxide, these forests contain more than 80 percent of the remaining uncharacterized gene pool on the planet—an absolutely irreplaceable human treasure.

DOMESTIC POLICY COUNCIL WORKING GROUP ON GLOBAL CHANGE

To develop a strong, coherent policy on global change for the United States, President Bush has asked me to chair a Cabinet-level Working Group on Global Change under the White House Domestic Policy Council. The Working Group provides an important Cabinet-level coordination mechanism on global change and is an important source of advice for the President. The membership consists of Cabinet-level representation by all relevant agencies plus the White House.

The President feels strongly that our domestic policy on global change should be based on the soundest scientific and economic information available. Accordingly, to acquire such information as quickly as possible, the Working Group called immediately for three specific studies: (1) an analysis of economic costs of global change and responses to it, (2) an analysis of private sector concerns, activities, and issues on global change, and (3) legal precedents for international agreements and conventions on the environment. Preliminary drafts of these reports have been presented to the Working Group for use in their deliberations. In addition, the Working Group has set up a number of briefings by top experts on the scientific, economic, environmental, and industrial aspects of global change.

CONFERENCE ON THE SCIENTIFIC AND ECONOMIC ASPECTS OF ENVIRONMENTAL CHANGE

In addition to the activities of the Working Group on Climate Change, the President has asked me, together with the Chairman of the Council of Economic Advisers and the Chairman of the Council on Environmental Quality, to organize a White House meeting of the three senior officials in science, economics, and the environment from a number of countries in the Spring of this year. The general purpose of the meeting will be to advance the quality and understanding of the scientific, economic, and environmental analytical tools and data necessary to confront international environmental problems, including global change.

The conference will have the specific goal of sharing among nations analytical techniques, data, and research in an effort to develop a common, integrated approach to respond to global change, taking into account the best information available on the scientific, economic, and environmental aspects of the issue. The conference will address a wide range of environmental issues, including global warming, ocean pollution, biodiversity, clean air, pure water, and conservation of natural resources, although the major emphasis will be on global climate change and, in particular, global warming.

PRESIDENT'S COUNCIL OF ADVISORS ON SCIENCE AND TECHNOLOGY

The first meeting of the President's Council of Advisors on Science and Technology (PCAST) took place last week at Camp David with the President. One of the topics under discussion was global environmental issues. I have asked PCAST to form a subgroup on global change that will correspond to the CES. Along with several activities that the CES is initiating to better coordinate with the private sector, this connection between FCCSET and PCAST should prove useful so that the Global Change Research Program can take advantage of the experience of the private sector and vice versa.

INTERNATIONAL RESEARCH AND POLICY-MAKING MECHANISMS

One of the major characteristics of global change is its necessarily international nature. Global change affects all nations and will require international study and cooperation.

Research on global change involves many international science programs, some that started before the most recent upsurge of interest in global change and some that are newer. Within the international scientific community are a variety of informal mechanisms for planning science programs. Often these informal mechanisms are used to plan the detailed scientific elements of a program. The subsequent activities are more formal programs—for instance, the World Ocean Circulation Experiment (WOCE), the Joint Global Ocean Flux Study (JGOFS), and the International Satellite Land Surface Climatology Program (ISLSCP).

The International Council of Scientific Unions (ICSU) is an international analog to the U.S. National Academy of Sciences (NAS). In 1986 ICSU established the International Geosphere-Biosphere Programme (IGBP), which is establishing a scientific agenda for global change from an international perspective. The U.S. participation in the IGBP is through the Committee on Global Change (CGC), a committee of the NAS sponsored by the CES. The CGC developed high-priority recommendations for new scientific research programs through its report "Toward an Understanding of Global Change: Initial Priorities for U.S. Contributions to the International Geosphere-Biosphere Program."

INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE

The U.S. government continues to support the work of the Intergovernmental Panel on Climate Change (IPCC), which is sponsored by the United Nations and the World Meteorological Organization. The three working groups of the IPCC, which are looking at the scientific aspects of global change, impacts, and response and mitigation strategies, met here in Washington this week at the Third Plenary Meeting to prepare their reports. The final papers of the working groups will be presented in August, shortly before the Second World Climate Conference in November.

In an address to the plenary session earlier this week, President Bush commended their activities and reaffirmed the United States' strong commitment to the IPCC process. He said, "We consider it vital that the community of nations be drawn together in an orderly, disciplined, rational way to review the history of our global environment, to assess the potential for future climate change, and to develop effective programs."

FRAMEWORK CONVENTION

The IPCC process is designed to provide input to an International Framework on global warming to take place next year. At the Malta summit last December, President Bush proposed that the United States offer a venue for the first negotiating session for a Framework Convention, and he reiterated that offer earlier this week. Using the results of ongoing research, the Framework Convention will be able to consider quantitative proposals for stabilizing emissions of greenhouse gases.

CONCLUSION

In this speech to the IPCC plenary session, President Bush said, "By being here today, I hope to underscore my concern—my country's and my own personal concern-about your work and about environmental stewardship, and to reaffirm our commitment to finding responsible solutions." The President also challenged the IPCC delegates to "deliver recommendations which strike a difficult and yet critical international bargain: a convergence between global environmental policy and global economic policy, a bargain where both perspectives benefit and neither is compromised."

I would like to echo the President's remarks in closing and underscore that only strong economies will allow nations to fulfill the obligation of environmental stewardship. I believe that the President's investments in improving our scientific knowledge and leadership in analyzing environmental issues will ensure our nation's ability to maintain this stewardship.

We in the Administration look forward to working with the Congress to develop a U.S. governmental response to this important issue. That concludes my prepared testimony. I would be happy to answer questions from the committee.

HEARING PROCEDURE

Senator **MIKULSKI**. First, just some ground rules. We are going to follow the 10-minute rule to be sure that each Senator has a chance to ask questions, and then if they need to be on their way, we understand and protect that.

A couple of things as we get ready to move into the questions. To respond to the fact that the Office of the Science Advisor will now be intimately involved with OMB, I think is an absolutely unprecedented opportunity, and also an agreement.

Last year, when we were working with the space station, and the funding, and Senator Garn and I shot the ramp with some extra change to work with, we went directly to Darman and Sununu, and we were, I would say, very cordially received, and everybody put on their green eyeshade and tried to help us.

PRESIDENTIAL COMMITMENT

But if we would have been able to even start then, it would have been even so much the better. The other—with the President forming this—I will call them the council of scientific elders, or whatever is the appropriate term, I think is also really unprecedented in peacetime, and the fact that you went to Camp David for a 3-hour brainstorm I think shows his interest and commitment.

I think what is so exciting is not only did you talk about the involvement of the private sector, but what I gather, is that we are really talking about a primary appropriate ceiling, civilian based science, and civilian-based research and development, which can go from research to idea, to product development, and so on.

Actually, I don't know of a President who has really focused that much on meeting with scientists, except perhaps when we were in the midst of World War II, and had to come to grips with the new approaches.

The fact that our President is meeting with them during peacetime is, I think, extremely important. This then is going to take me to some questions on both policy and on the research aspect.

It is not my habit to hold up a book and wave it, but what I do have here is a GAO report that just came out yesterday, at the request of Chairman Dingell, our cousin, in the House.

NATIONAL POLICY

What he talks about here is the problems of policy, and that the national policy according to the GAO, according to this, is that national policy has not yet been established, and agency responsibilities not yet defined, and, therefore, not moving with the same haste that perhaps some had thought.

Now, that is the framework of the question, and I know that you probably have not seen the report——

Dr. BROMLEY. No; not yet.

Senator MIKULSKI [continuing]. It is not meant to trick you, or whatever, but my question then is, Could you tell me what is the policy structure, in terms of the way that you are going to arrive at it, who has been tasked to do it, and I think that one of the disturbing things is that we moved into the President's remarks on the international meeting last week, and it looks like we were lurching around from adviser to adviser.

WHO IS IN CHARGE?

That is not to diminish you, Dr. Bromley, but it was meant to find out who is in charge. Is it the scientist guys, like you, or was it the Chief of Staff; and, again, this is not—I don't care, but what I do care about is that we are going to get a dollars' worth of science and action out of whatever we spend, and that is what I want to probe in this direction.

Dr. **Bromley**. Your concern, Madam Chair, is entirely appropriate. Let me try to respond to this question of who is doing what. Let me begin by commenting on the impression that was created—and I quite agree that it was created in the press that no one was in charge with respect to this last Presidential speech.

Unhappily, when the system leaks, as it does frequently, what comes out——

Senator **Mikulski**. Democracy.

Dr. **Bromley**. Yes. [Laughter.]

What comes out, Madam Chair, as you know, sometimes bears not too much relation to the actual facts. In this particular case, what we were engaged in is what goes on with every speech that a President makes. There are drafts that circulate, and there are disagreements about various parts of them, but disagreements get ironed out.

I would emphasize that in this as in several other cases, for example, I usually find myself painted as opposed to Bill Reilly. We cooperated very closely on this, and so did Jim Watkins.

I want to try to lay to rest some of this impression that we spend most of our time at one another's throats. There are a lot of people who apparently find that it is an amusing activity to try and split off and divide members of the White House staff.

At the moment, the President has asked his Domestic Policy Council Working Group to be the focus for policymaking, and that is agreed upon by everyone involved; by Bill Reilly from EPA, and by everybody else.

We meet on a frequent basis, and we really do try to make those policy decisions as required; to provide scientific input to those activities, what we are doing right at the moment is refurbishing and revitalizing the whole FCCSET structure. That will allow us to bring together all the Government agencies under an expanded Committee on Earth Sciences, so that we get essential intragovernmental cross-communication.

I am already asking PCAST to put together a panel drawn from the private sector—of really distinguished private sector scientists, and industrialists—who will similarly focus on these questions of global change. Since I chair both groups, it will be my responsibility to make sure that they come together from time to time, and that we really do get the best possible input that we can get for the policy that will be recommended by the DPC working group. Our recommendations go to the Domestic Policy Council that Attorney General Dick Thornburg chairs, and from there directly to the President. That is the policy chain.

COORDINATING ROLE

Senator **Mikulski**. Doctor, which individual, if there is one, within the administration, has the President tasked to coordinate and develop specific governmentwide policy options on global warming?

Dr. **Bromley**. Me.

Senator **Mikulski**. So if we had only one call to make on this, you would be the person?

Dr. **Bromley**. That is correct.

Senator **Mikulski**. You are the person——

Dr. **Bromley**. I have to pull together——

Senator **Mikulski**. Essentially, you are the science czar.

Dr. **Bromley**. I hate that word, Madam Chair. [Laughter.]

At the moment I am responsible at the request of the President, and it is my responsibility to pull together the opinions throughout the senior administration.

I do want to emphasize that we have a very close cooperation among the major agencies here, which are EPA, and the Department of Energy, and the Department of Commerce, with NOAA in particular; and those agencies play major roles.

But other agencies across the whole spectrum play important supporting roles and OMB is, of course, a central player.

Senator **Mikulski**. Geological, and science foundations and so forth?

Dr. **Bromley**. Yes.

RESEARCH PROGRAM DOCUMENTED

Senator **Mikulski**. Now, this wonderful—the Committee on Earth Sciences has produced a really splendid book on our research program, and I think anyone can pick it up and use it, and it is in plain English, and anyone who is interested in this can do this.

I think that it adequately summarizes it, and it gives an accurate picture. Is there underway a plan to essentially put out a coordinating policy for this, and actually using this for the basis of hearing what budget work we are going to be doing? So I essentially have a little manual that I can refer to, you know, to begin to work on our concerns.

Do you expect to produce a comparable one on policy, and if so, when could we expect it?

NEED FOR NATIONAL ENVIRONMENTAL POLICY STATEMENT

Dr. **Bromley**. Two things, Madam Chair. Later in the spring, what we want to do is the same as we did last year, and provide you with a much more detailed followup which treats budgetary and scientific aspects, but does not do what I think you have in mind, namely a national environmental policy statement, or something of that sort.

That is something that we are discussing at the moment.

Senator **Mikulski**. So, you really need to make a statement?

Dr. **Bromley**. Let me say that there are many of us who feel that it would be a good idea.

Senator **Mikulski**. What would be the roadblocks to achieving that?

Dr. **Bromley**. Probably—and as is always the case in getting a single statement in a major cross-cutting field—the problem would be simply that of developing the consensus, so that we can make a statement with which everyone will feel comfortable.

Senator **Mikulski**. Doctor, with the difficulty in getting this consensus, and not based on the problems with science, or with issues concerning economics, and like we are doing now, to arm wrestle the Clean Air Act in the U.S. Senate, is that the solution?

ECONOMIC CONSIDERATIONS

Dr. **Bromley**. Senator, the first order of questions at this moment are not scientific. While it is very important for us to move forward with the science, as I have suggested here this morning but in terms of our policy in the immediate short range, we clearly have strong economic considerations that must play a role—and we don't know enough of the answers yet.

We are close, however, and a draft report from the Council of Economic Advisors exists, but I have not seen it yet. We also know that similar economic modeling activities are being mounted in other countries preparing for the White House Conference that I mentioned earlier, and by spring we will have a much better view of this whole issue than we do now. This is true not just in this country, but in a number of others as well and we will be coordinating to make sure that we really get the best insight out of all our activities.

Senator **Mikulski**. So, what you are saying is that there are those who would like to have a national environmental policy on a topic like global warming?

Dr. **Bromley**. Yes.

Senator **Mikulski**. The issues are the need for more science, which we will talk about, but then also the economic ramifications.

Dr. **Bromley**. Exactly.

NEED FOR ENERGY EFFICIENCY

Senator **Mikulski**. If I could then go back to your testimony, which was one of the questions in terms of economics, is if we begin to—one of the recommendations that I heard was to use—to strive for more energy efficiency?

Dr. **Bromley**. Yes.

Senator **Mikulski**. Be it conservation that ordinary citizens could take, and the improvement of processes, both in manufacturing and even in terms of the machinery we use, so that we use less energy.

Dr. **Bromley**. Exactly.

Senator **Mikulski**. I am going to come back to the question of policy, but when we talk about the economics, we are not necessarily talking about throwing our society into disarray or dislocation.

Dr. **Bromley**. Not at all.

Senator **Mikulski**. It is by using ourselves smarter and better that we become more efficient, and, therefore, it is cheaper, less energy and it is cheaper; and therefore it has its own cost benefit. Am I following your argument here?

Dr. **Bromley**. You are entirely correct, Madam Chair. I think that it is safe to say—and I think that most people would agree—that through really aggressive conservation we could perhaps stabilize our emission of carbon dioxide.

If we are going to reduce our emission of carbon dioxide, however, then we face much more draconic measures; measures that would require doubling the mileage that we get from our automobiles, measures that would require major taxing of gasoline, taxing of the use of electricity and so on.

My own feeling is that I would not feel at all justified initiating programs of those kinds unless I was quite sure that the requirement for their disruption of our economy really could be demonstrated. It could not be demonstrated with what we know now.

PUBLIC CONSCIENCE RAISING

Senator **Mikulski**. Well, I absolutely agree with you. I know that back in the Carter administration, when I worked on the Special Energy Committee to move that President's policy, the Schlesinger approach was to raise the cost of energy, and, therefore, do conscience raising with the American people.

But I will tell you that the American people's conscience has already been raised, and they believe that if you give us $1, we will spend $2, and we are not—you know, I don't see that, and I see it that they will turn down their thermostat and up to a variety of other practical kinds of things.

Senator Garn, I wonder if you would yield to Senator Nickles.

Senator **Nickles**. Madam Chair, thank you very much. Dr. Bromley, thank you as well. Doctor, I will mention just a couple of things. One, I am surprised at the enormous increase in the budget.

I don't know if we can afford those increases, because I know that we have wrestled in this committee with a lot of tough decisions on funding, whether it be in NASA, or whether it be in housing, or other areas, and you are competing with NSF and some other areas that we are funding.

You are also getting money from seven bureaucracies as I see. I heard you mention coordinate and in some way pull their heads together and speak with one voice, but I also see that as next to impossible.

SEVEN BUREAUCRACIES INVOLVED

You are dealing with seven bureaucracies, and I wish you well in that regard, but there should be some studies. I also heard you mention the word, "economical." Particularly when you get into the policy side of the issue, we want to use things that make sense economically.

I would underline that, but I also have some reservations. I see this as an enormous increase, but when we get to making difficult decisions and Gramm-Rudman constraints, et cetera, I don't know if we can afford that type of increase.

I do hope that we will make decisions with a little common sense, and, hopefully, you will be able to coordinate the various agencies, but I don't know if that is the right way to do it.

I would hate to think that we have seven different agencies that are all working on U.S. global policy. That seems to be very duplicative to me.

Dr. **Bromley**. May I just comment on that, Senator. In this case, what this group does is not to develop the policy. What they really do is to ask the question, what are the gaps and the uncertainties in our scientific understanding.

The coordination that is done in that committee is to make sure that the funding that you do make available to us is used in the most effective fashion.

In coming up with this CES booklet, for example, OMB and OSTP, together went back to the agencies after we had brought in the first plan, and said, "Look, we recognize just as you do the tight budgetary constraints that we are going to face," and so we asked them to come back with contingency alternatives, and to really take the whole plan and look at it at various funding levels to tell us where they would cut, and what they would remove at various levels, to still get the best information input from a given expenditure.

What you see here is not by any means the top funding level considered. That was simply not accepted for the reasons that you just mentioned. But policy is not made at the CES level.

SIGNIFICANT INCREASE

Senator **Nickles**. Well, I appreciate that, but you go from $650 million to $1.034 billion in 1 year, and that is an astronomical increase, and possibly unparalleled in any other account.

There may be another account, but it would be a small account, and so you are talking about significant dollars, a significant increase.

EOS PROGRAM

Dr. **Bromley**. The major increase, Senator, is the one associated with the NASA program that will get us the Earth observing satellites [EOS].

Senator **Nickles**. What program is that again?

Dr. **Bromley**. That is the EOS Program. It includes two polar platforms, each of which carries some 15 independent instruments that view a particular point of the Earth's surface together as the satellite moves about the Earth.

Senator **Nickles**. So, for NASA, is that a one term, or are you looking at that amount level over many years?

Dr. **Bromley**. It is going to be an expensive program, and it represents a substantial commitment over a number of years.

Senator **Nickles**. Let me just make a couple of other comments. I noticed in Forbes that they had an article on global warming panic, a classic case of overreacting. Have you reviewed that article?

Dr. **Bromley**. Yes.

Senator **Nickles**. Do you think that there is substance to it?

Dr. BROMLEY. Like all such articles, perhaps the statement is a little overblown.

Senator NICKLES. Is the other side on the pro-global warming, do they overblow on occasions?

Dr. BROMLEY. Absolutely. All sides tend to overblow a little—and in some cases, a lot—on occasion, but the key point here is that I think we are approaching a more rational centrist position, and if you have noticed publications over the last 6 months, you will have noted that they have moved away from those that spoke entirely about a crisis on our doorstep.

A few say, "Wait a minute. There isn't any crisis here," and then we have those that are now saying, 'Look, this is a serious problem that deserves the serious attention of this and other countries." I agree with this latter group.

AUTO EMISSIONS

Senator NICKLES. You mentioned the problem with CO_2, and I heard you mention conservation, and there are many people who would like to see higher fuel economy standards mandated on all automobiles, and I am not one of those, and so you will know where I am coming from.

If you eliminated all of the automobile CO_2 production in the United States, how much reduction would you have on a global basis?

Dr. BROMLEY. It would be very small.

Senator NICKLES. I understand that it is about 2 percent.

Dr. BROMLEY. Something like that. I would also have said 2 percent, but there is probably a plus or minus 1 percent uncertainty. Somewhere between 1 and 2 percent.

REALISTIC GOALS

Senator NICKLES. I would—and, again, in this idea of using some economic realism in making decisions, you could have some proposed legislation that would increase standards to 40 or 50 miles per gallon, which could increase fuel economy, but in all likelihood in my opinion it would decimate some industries.

We could pass a law that would make it 60, and just tell everybody to ride bicycles, you know.

Dr. BROMLEY. Frankly, if we go the way that you have mentioned, Senator, I feel that we are handing our automotive industry to other countries.

Senator NICKLES. There is no question about that, and I just want a little common sense when we start talking about goals and what is obtainable, and what can be done.

Plus, when we get into the issues of safety, and you get into the issue of lives, and so on, a little common sense would go a long way. I appreciate your presentation before the committee today. Thank you, Madam Chairman.

Senator MIKULSKI. Thank you.

Dr. BROMLEY. Thank you, Senator.

Senator MIKULSKI. Senator Garn.

Senator GARN. Thank you, Madam Chair.

Dr. Bromley, first of all, let me say that I am pleased that Senator Mikulski called these hearings, and particularly that you are not here on your first visit before this subcommittee to comment about the budget, and talk about major policies, your global climate change, and I think that is significant.

I also agree with Senator Mikulski. I am very pleased with what the President has recommended, and what I think is a new emphasis on these particular areas, and I have heard nothing but good reports about you, and your abilities, and universally, everyone that I have talked to in the scientific community has nothing but praise, and I was pleased to listen to you today, and I think you are on the right track.

Having said all of that, however, I still sense great frustration as I listen to you talk, and answer Senator Mikulski's questions, because I have no doubts about your sincerity in trying to pull things together, but as I have served through four Presidents now, and I have seen domestic councils and White House Staffs grow, and even though you are an assistant to the President, there are a lot of assistants to the President down there, and this really disturbs me.

DRAMATIC GLOBAL CHANGES

As one who has looked back at this Earth from space, and I am certainly not a scientist, but I had the Earth observation classes at NASA, and learned something about geography, and oceanography, and I saw erosion coming out of rivers all over the world, and I observed the deforestation in Brazil and in other places.

It is a dramatic thing to view with your own eyes, and so I think that Senator Nickles is probably correct that there are always extremes, but nevertheless there are some severe environmental problems, and we tend to talk more about the local solid wastes facility and toxic waste dumps, and not that those are not important, but it is certainly my view from having had a real view that there are some dramatic changes taking place on a global basis, that while most countries talk about, we are not doing very much about.

POLITICAL CONSIDERATIONS

So, if you look at an organizational structure, it is unfortunate that the longer you are here, you will find out that political considerations will take effect, and so somebody that has no scientific knowledge at all is going to read your reports and sit there and second guess it, and then it has to go to somebody else, and weeks and months go by.

These are issues that I don't think should have any political overtones at all. I think that they are too important. So, I don't know how you cut through all of that. If I had my way, what I would do is not just have an assistant to the President.

PROPOSED DEPARTMENT FOR SPACE, SCIENCE, AND TECHNOLOGY

We have a new Cabinet officer for veterans, and one is proposed for the EPA, and I think we ought to take a much broader view. I would like to see a Secretary in a Department for Space, Science, and Technology.

When you look at the importance, not only in what is happening now, but in the future in science and technology in general, so that we could eliminate—and with OMB and all the different agencies that you work with, and to finally get to the President to make a decision—and Senator Mikulski was talking about that, every administration, and it seems to grow as time goes on, and I don't see any way to cut through all of that unless you finally decide that there may be a more important department for space, science and technology.

I always get accused of—in talking about NASA, it just is not a space station, and it is not just a space shuttle. It is the National Science Foundation, and it is training science and math teachers, or are we training enough engineers and scientists in this country.

So, your point about that is dramatically no, no, we are not, and I think our future as a superpower depends on what we do in these areas, because our advantages have always been in our science, and we are losing it.

If you get a united-Germany, and that talent over there, and you get Japan, and these budget amounts, while Senator Nickles is correct that they are difficult, they're miniscule compared to what we need again, and not just in NASA, but in space, science and technology across the board.

SCIENCE NEGLECTED

There is nothing that I fear more than what has taken place over the last decade or so, or longer than that, because where I have really been involved in it is the apparent lack of interest in science.

We sit back and say, "Well, we are talking about going more to the service industries." Well, that's fine. We want to be servants of the whole world? Well, I don't. I would like to still be the leader in technology, and manufacturing, and all of those things.

So, the issue isn't really very broad, and I have advocated that, and nobody listens, but I really do think we ought to have a separate department for space, science, and technology.

COMMITTEE STRUCTURE QUESTIONED

I also don't think after having been on this committee for a long, long time that science should have to compete with housing. This is a committee, when they set up the structure, it got everything that was left over.

Most of the other committees, the appropriations subcommittees, are for a particular purpose, or department. Well, I don't know how HUD or Veterans, and what relationship they have with the National Science Foundation and the reason it is called HUD and an independent, is because after they had gone through the rest of them, well, everything else goes into one more subcommittee.

I am not knocking how that is, and that is an important aspect in the Veterans, and I am a veteran and all of that, but I think we do need to change our budget processes as well, because I don't think we ought to have to—and in the broad sense you would in any event, but in the normal sense this committee ought not to have to choose between a solution of global warming and low-income housing, and those are tough choices.

We need both, and if so, both on the executive level and on the congressional level, we have structures set up that are not helpful to solving these problems, and so we need a great deal more money. I am not on the alarmists side, but on the other hand, having viewed the position that I have, there are serious, serious problems.

Even the centrist position is a serious, serious problem. It is not going to affect you and I at our age, but I have six little grandchildren, and it is going to affect them.

So, more than questions, I suppose, I have a plea for any way you can help us cut through the bureaucracy, and if you can yell and scream, and come to me or Senator Mikulski, and say, "Hey, we are bogged down."

We have some green eye shade idiot down at OMB that doesn't know anything about anything, and he is a numbers cruncher. That is my biggest problem with OMB. They are just number crunchers, and they don't understand policy.

They are given some numbers, and they sit there, and they punch them back and forth, and then they interfere with somebody who has the scientific background, saying, "No, you can't do that."

There is no reason, other than two different sets of numbers.

NEW SPACE FRONTIER

Dr. **Bromley**. A couple of comments. First of all, let me say that I really agree with almost everything that you have said. With respect to the administration, as you know, we have the Space Council, of which I am a statutory member, chaired by the Vice President.

The intent, because the President shares many of your views, was to elevate the whole question of where we go in this great new space frontier to that level; the membership of the Space Council is an active one drawn from all of the relevant agencies.

We are trying, at least, to cut through a lot of the bureaucracy that you quite correctly described. Let me also say in defense of Dick Darman that he is prepared to really sit down and talk about the nonfiscal aspects of our space and other programs, understands them, and is sympathetic. I find it a great pleasure working with him, and we are very fortunate in having him involved in these decisions.

Senator **Garn**. Well, he was sympathetic. Senator Mikulski and I both talked to him at great length last year, but we want sympathy turned into some help.

Dr. **Bromley**. Yes.

Senator **Garn**. We get a low 302(b) allocation and we have to make these tough decisions. Let me make one other comment, too, and I want to send this message very, very strongly. I am going to illustrate it very specifically.

FOLLOWTHROUGH LACKING

Every President since I have been here, since Ford and Carter, and all the way through, generally sent good requests in these areas, some better than others. But they make the speeches, and they are for this, but then they don't follow through with the type of lobby help that we need.

Dr. **Bromley**. That's true.

Senator **Garn**. Now, we begged last year for help, and every time I talked to the President, yes, he was helpful, but it didn't really trigger the kind of effort needed.

A specific example of what we need is what happened 2 weeks ago. I was down at the White House for a breakfast on the China student issue. I made the comment that I was undecided; and I had not been back in my office 15 minutes before I got a call from Senator Simpson, and another 10 minutes I got a call from Jim Baker, and then I heard from Brent Scowcroft, and then I got a call from Bob Dole, and then the President called me himself, all within a period of a half-an-hour.

That is the kind of lobbying effort that I want on space, science, and technology. [Laughter.]

Senator **Kerrey**. For what it is worth, no one called me at all. [Laughter.]

Dr. **Bromley**. Let me say both that I agree with you and that this committee, Madam Chair, has what I see as one of the most difficult jobs of any committee in the Congress, in balancing Housing and Urban Development, and Veterans Affairs, with NSF and NASA.

BIPARTISAN EFFORT CALLED FOR

I would emphasize to you that while I feel that it is very important for my Office to build bridges with OMB and other parts of the White House, it is terribly important for us to be able to work on a continuing basis with your staff and with you. It is to that end that I have come up and had—from my point of view—a very excellent meeting with your staff.

I want to continue to do that, and I want your staff to feel free to contact us. This is a national challenge, and only if we in the administration, and you in the Congress, can really work together will we succeed. These areas really must be addressed as bipartisan efforts, because they are really investments in our national future.

I want to work with all of you on these activities, and together I think we can do something worth while.

Senator **Garn**. Thank you, Madam Chair.

Senator **Mikulski**. Senator Kerrey.

Senator **Kerrey**. Mr. Bromley, let me first say that I, for one, am still trying to understand the whole issue of global warming, and it did in some ways sort of come on me, as I assume it has on an awful lot of other people.

I must say that in reading just three or four of the pages that you have put out here in your testimony, and it seems to me with all due respect, that what you are trying to do is walk a fairly thin line between people who are being critical of the administration for not going fast enough, and the need to try and sell those of us who are trying to decide whether or not to appropriate the full amount that you have requested.

I fear, sir, that you have erred a little bit too much, at least as I read this thing, on the defensive side against those who are being critical.

USE OF FOSSIL FUELS

You use, for example, the words, "extensive use of the fossil fuels." I mean, I have not been around very long, but I know that the United States of America is doing a bit more than just an extensive use of fossil fuels.

I mean, compared to the rest of the world, it is a bit more than just extensive. I mean, I am not putting out 5 tons of carbon a year by accident, and so if you are going to create the kind of urgency that I think is necessary in order to work on this thing, and work on the problem and particularly to put the kinds of resources into it, it seems to me just as one Senator here, that you are going to have to move a bit more toward the side of trying to describe not in an alarmist way at all, but trying to describe a problem that permits me to vote yes on the distribution of taxpayer dollars to you and others who are going to try and solve this problem.

Let me ask just one—I mean, I am just expressing a concern, and I won't actually put it in the form of a question. I just expressed a concern, so that you can factor this in as well.

ELITE GROUP OF ADVISERS

You said that you have an advisory group advising on policy. I must tell you with all due respect with the three categories that you have listed that I am not encouraged that the policy is going to be good when you say you are going to have scientists, and industrialists on the Committee.

I mean, I just urge you to consider that one of the things that has to occur here is that the people themselves have to understand and trust your policy recommendations.

That is a fairly elite group of people that you selected. I mean, obviously you need scientists and mathematicians and industrialists on this group, but I think you need broader representation on it, and I would just urge you to look at that.

In fact, again, with all due respect, and I know that when you put together this Committee on Earth Sciences that you've got to have somebody from the Department of State, and somebody from NSF, and you have other requirements. But, you have one woman on the group. One woman on the group.

You say, "Well, that is not a big deal." It is a big deal to me because these people will be developing recommendations about what our policy ought to be. It is important to me personally—and again, I pass no judgment on the capabilities of the committee—but it is important to me that the recommendations come from a fairly good cross-section of America.

Dr. **Bromley**. Senator, I agree with the points that you are making. I would only emphasize that the Committee on Earth Sciences, for example, does not make policy. Its task is to give us the best scientific and technical advice that we can get, and when you——

Senator **Kerrey**. Please, please. If advice is limited, then the policy will be limited. I mean, I have a staff of 25 people, and it is very important for me to consider from whom I am going to receive advice, because it will have an impact upon policy development.

Dr. **Bromley**. Sir, I agree with you, but the Working Group that is going to recommend the policy in this global warming area gets advice not only from CES, but we are also meeting with groups of senior environmentalists across the country, with people in industrial organizations that are involved with global change across the country, with scientists drawn with the help of the national academies from broad sectors of the public.

Senator **Kerrey**. Doctor, please, you have persuaded me that you are balancing this with other input, and I am greatful for that. I am glad that you are doing that, but the Committee on Earth Sciences is an organization that has a substantial amount of—will have a substantial amount of influence on policy, a substantial amount, and more than most other people that you consult.

COMMITTEE REPRESENTATION IMPORTANT

If they have to vote, and make a decision, as they most assuredly will from time to time, it seems to me that the kind of representation that is on that Committee is a very important thing for you to consider.

I know that you have sort of been pulled out the other ranks, but I am just telling you that from personal experience of doing this, that I found it to be very important to factor in other considerations other than just sort of scientific knowledge, and industrial knowledge, and technical knowledge, because we must sell the recommendations.

The recommendations must ring true to the American people. It is not going to work if we do a lot of homework and we figure out what OSTP, and CES, and GCM, and CFC, and EOS, and all the other acronyms that you have in here. We figure out what they mean, but the American people don't understand it.

Dr. **Bromley**. Your point is well taken.

COMPOSITION OF WORK FORCE

Senator **Mikulski**. Senator Kerrey, you make an excellent point, and it comes to an issue of what work force is in the Federal Government, if any, and at every hearing since I have been on this subcommittee I have asked the major agencies that we fund what is the status of women and people in power, in positions over GS-12.

We will share those numbers with you. They are quite dismal; and, you see, what you have here on this listing are people who come up through these agencies, and this is a reflection of not necessarily Dr. Bromley's selection, but their selection, internally, and I would hope that as we go through those hearings we ask those questions relative to work force and promotion, because there are very talented people that run into glass ceilings of promotion, and, therefore, they are not moved up.

Senator **Kerrey**. I would just say directly that you need to get more women on that Earth Scientists Committee.

Senator **Mikulski**. Senator Kerrey, we also need to get more women and people of color in top positions in EPA, and NASA—and I can't go to a meeting where I am the only person in the room that looks like me. [Laughter.]

Senator **Garn**. I do it all the time. [Laughter.]

Senator **Mikulski**. Well, I will tell you that it is very frustrating to me when you oversee a portfolio of $60 million, and you think that nothing has happened over the last 20 years in this country. So, I share that with you.

Senator **Kerrey**. I must add some additional detail. I mean, when you say scientists, mathematicians, and industrialists—I mean, this will affect working people. The recommendations will not only be paid for by the working people, but at the end the regulations, or whatever we put out, whether it is the maintenance of the current cap standards that Senator Nickles wants, or whether we have increase in this as Senator Kerrey wants—I mean, whatever we do, it will affect the people that I don't see being necessarily represented on this.

Dr. **Bromley**. [Nodding head.]

Senator **Kerrey**. I see you nodding, and I have been redundant in making the point, but I wanted to make it.

Senator **Mikulski**. Senator Grassley, do you have any questions at this point?

Senator **Grassley**. Yes; I have several, but I am going to submit them in writing.

Senator **Mikulski**. OK.

Senator **Grassley**. The only point I would bring up, and there naturally is something that caught my interest as we talked about agriculture, livestock, methane gas, et cetera. You know, we can make a lot of fun out of it; yet it is a very serious issue.

Dr. **Bromley**. Sure.

Senator **Grassley**. The only thing I would ask for as you consider recommendations and your concerns about that on global warming, if you take the wide environmental debate that goes on in the country, and you see in agriculture a lot of us trying to find ways of cutting down on the use of commercial fertilizers and pesticides, and the necessity or the desire to increase crop rotation, and all the things that would enhance the environment, as well as probably the economy, livestock is a very important factor in that.

We want to make sure that you don't come up with some recommendations that on the one hand solve one problem, and take care of one problem of the economy, or rather the environment, and creates other problems in what we are trying to do in other committees, or through other programs.

I have a question on that in here, and one other thing that I might ask you, because you said that the latest statistics on the warming and its impact upon oceans, and the rising of the oceans, you said it could be off 12 to 18 inches.

OCEAN LOWERING

Do you mean that there is a possibility we could have a lowering of ocean by 6 inches if you apply that equation?

Dr. **Bromley**. No; not really.

Senator **Grassley**. Oh, OK.

Dr. **Bromley**. At the moment, in the near term, I don't see any possibility of any lowering, but over geological periods, of course, there have been dramatic lowerings in the ocean, and if we go into glaciation, we will get lowerings by hundreds of feet, but that is certainly not going to happen in any future that is of real concern to any of us.

Senator **Grassley**. Well, on that figure, near term, there isn't that possibility, but I read your deviations and there are variations to allow that.

Well, Madam Chair, I will just submit my questions. Thank you very much.

Dr. **Bromley**. If I may say, sir, we are sensitive to the issue that you raised.

Senator **Grassley**. Madam Chair, I will submit the rest of my questions in writing.

Senator **Mikulski**. Certainly. Just to move along, because I know that the time is late, and many of us have duties actually, I think the fact that—in addition to the chair and the ranking minority, that three other Senators appeared shows the interest in this topic.

I think this approach in trying to look at questions related to energy strategy—because one of the things that emerged in your testimony, and in ongoing conversation, was the link between energy strategy and global warming.

INTEGRATION OF GLOBAL WARMING POLICY INTO ENERGY STRATEGY

Therefore, my question is, Has the President given instructions to Watkins on how the global warming policy is to be integrated into the energy strategy, and when that is released, what can we look for in terms of its environmental impact as we talked about earlier, to strive for efficiency? Is that on the way?

Dr. **Bromley**. I can't really speak to specific instructions that the President may have given Jim Watkins, but I do know—and as I mentioned, I am cochairing a meeting with Jim all day tomorrow—that we will talk about the scientific and technical aspects of this new policy, and we have spent a lot of time on energy conservation and Watkins has been one of the most active members of my DPC Working Group.

NATIONAL ENERGY PLAN

From the very beginning there has been a clear recognition that one of the major components of our response to potential global warming is going to be through this national energy plan.

Senator **Mikulski**. When will it be released, Doctor?

Dr. **Bromley**. My understanding is that it will be available in draft form this spring, and DOE has now held meetings all across the country—Hawaii, Florida, and all through the Midwest—I think there was one in Alaska—to address the issues and Senator Kerrey had a very good point.

What we are all trying to do with this national energy plan is to really have open forums so that the people who are going to be ultimately concerned with its impacts throughout the country are going to have an opportunity to come and be heard.

The global change aspect, and the connection between environmental futures and our energy utilization is very well recognized, and will clearly form a substantial part of the new energy plan.

CHINA FACTOR

Senator **MIKULSKI**. Well, we will look forward to getting it as soon as possible. This takes me to an international question. We are talking about the United States, but there was China television here, and I am sorry that I didn't get a chance to ask this question then, but while we are busy really talking about the steps that we can take with ourselves, and policy objectives, there is a country with over a billion people in it called China, and that their primary source of energy is fossil fuel.

My question is, No. 1, is China a participant in these international discussions, because while we are doing this, all of the efforts of western democracy could be eclipsed if China is not engaged.

Dr. **BROMLEY**. That's correct, Madam Chair. Your point is absolutely correct. China is becoming involved in the international discussions, and China, for example, will be among the countries invited to participate in the White House Conference later this spring, for just the reasons that you mentioned.

WINDOW OF OPPORTUNITY

If you will permit me, Madam Chair, I think that you just touched on what I consider a very important window of opportunity that we have in this country.

There are countries like China, like India, that if they proceed along their present trajectory to industrialize and develop, using the coal that they have, then almost anything we could do concerning global warming would be swamped completely.

It seems to me that we have an opportunity to take some aggressive steps to make sure that for countries in the Third World—and in Eastern Europe where the problem also exists—we make available the best technology that we know about to allow them to minimize their consumption of fossil fuels, while continuing their industrialization and the development.

That, to me, means that we have to provide the technology, the know-how, and probably also some support to make it possible. If we do that, I see the potential advantages of being, first of all, a tremendous help with respect to the environment; second, a very positive political reaction; and, third, access to what will be an enormous market for our industries.

If we wait until we are pressed into such a response by international pressures, then we will still have the same impact on the environment, but we will lose the political positive impact, and we will certainly lose a large fraction of the market share that would otherwise be ours.

Senator **Mikulski**. Well, Doctor, first of all, I could not agree with you more, and certainly as we move through this appropriation, I can look forward to this advice as we even deal with our foreign neighbors.

POOR AIR QUALITY IN EASTERN EUROPE

In a recent trip to Eastern Europe, the air, particularly in Poland and East Berlin, was filthy. So, we can talk more about that. Let me just go then to one more question, which again goes to our participation in world conferences in CO_2.

When we met at the Dutch Ministerial Conference, we agreed to stabilize as much as possible CO_2 emissions, which of course many people feel lead to the greenhouse effect. Are we still committed to what we said in The Netherlands, and when do we intend to comply and do we intend to do so? I believe that we agreed to stabilize by 1990.

Dr. **Bromley**. No; I am sorry, Madam Chair, but at Noordwijk——

Senator **Mikulski**. Excuse me, the policy.

Dr. **Bromley**. At Noordwijk, a great many of the countries present were prepared to commit, at that time, to stabilization by the year 2000. We took the point of view that was shared by Japan and the Soviet Union that we did not know at that time, first, how we would do it, and, second, what it would do to our economy.

We felt that we could not sign such an agreement at that time, and we discussed this with the other countries present; we convinced some of them that they, too, would have real difficulties, and that we should all know more about them before we made any such agreement.

The communique that was issued said that we agreed that it was desirable to stabilize CO_2 emissions as soon as possible, but we did not specify a time.

Senator **Mikulski**. So, we agreed that it was desirable?

Dr. **Bromley**. Yes.

Senator **Mikulski**. But we did not agree to their framework, which was to——

Dr. **Bromley**. A time certain.

Senator **Mikulski** [continuing]. Have a kind of commitment to stabilization, and then a time certain for policy by 2000.

Dr. **Bromley**. Yes.

Senator **Mikulski**. Did we agree to the declaration?

Dr. **Bromley**. From Noordwijk?

Senator **Mikulski**. Yes.

Dr. **Bromley**. Yes.

Senator **Mikulski**. Well, I am getting my questions from your declaration, and maybe what we could do——

Dr. **Bromley**. Frankly, I have not looked at the document for some time, and so if someone would just read the——

Senator **Mikulski**. Senator Garn, did you have another question?

Senator **Garn**. No, no; I have no more questions.

Senator **Mikulski**. OK. In the declaration it says we agree that it is timely to investigate quantitative emissions and to target the limit, and to reduce emissions, and encourage the IPCC—to include a target of options.

Then we go on to say that we recognize the need to stabilize, while ensuring stable development of the world economy, CO_2 emissions and emissions of other greenhouse, not controlled by the Montreal Protocol.

And that we agree that it should be considered by the IPCC and the Second World Climatic Conference in November of 1990.

Dr. **BROMLEY**. Yes.

Senator **MIKULSKI**. In the view of many industrialized nations, such stabilization of CO_2 should be achieved as a first step at the latest by the year 2000.

Dr. **BROMLEY**. We agreed——

Senator **MIKULSKI**. And so when we signed the declaration, is that what we agreed to?

STABILIZATION SOUGHT

Dr. **BROMLEY**. No; there was no signing, Madam Chair. It was just a consensus document that the Conference Chairman issued, but we did agree to that statement as a statement of fact, and we are working towards that stabilization as a goal.

Senator **MIKULSKI**. But in your mind, or the agreement in your mind, and I will gather that if it is in your mind, that then is the mind of the administration; that we agree that it was desirable.

Dr. **BROMLEY**. That's correct.

Senator **MIKULSKI**. And that it was a desirable goal, and not a policy mandate.

Dr. **BROMLEY**. Not a policy mandate, and we did not agree to stabilize at any specific time. We agreed that it was desirable to stabilize if we could do it without disrupting our economy.

Senator **MIKULSKI**. Then, where are we in that process of compliance as we then said we would comply?

Dr. **BROMLEY**. We simply said that we agreed that there was a need to do it, subject to those conditions, but we didn't give a date.

Senator **MIKULSKI**. We did agree to cooperate?

Dr. **BROMLEY**. We did agree to cooperate; absolutely.

Senator **MIKULSKI**. And we did agree that——

Dr. **BROMLEY**. Our best efforts.

Senator **MIKULSKI**. Our best efforts. OK. So, where are we in formulating our best efforts?

Dr. **BROMLEY**. We are, I would say, Madam Chair, somewhere on the order of halfway along, because we have gotten our first draft and response from the economists and from the private sector, and on that basis we will be able to begin to make specific policies about whether we can by some certain date agree to stabilize; and whether we can agree—by any date—to the kind of reductions that are being discussed—20 percent reductions and so on.

We are not there yet, but we will be there in time for us to participate in a fully cooperative fashion at the Second World Climate Convention, which is in late October, and at the first negotiating session for the Framework Convention, which the President has offered to host here in Washington. It could occur as early as October, or as late as January of 1991. It is in that timeframe.

SCHEDULE FOR ACTION

Senator **Mikulski**. So, is there a schedule then for action, or a timetable?

Dr. **Bromley**. Yes; there is. Let me just run through it very quickly. The IPCC meeting that was held here this week was to finish draft reports. We are active participants in the three working groups on the science, the impacts, and the possible responses, respectively. The United States chairs the response committee.

These final reports will go before the full IPCC in August, and IPCC will then issue its documents that will be the input for the Second World Climate Convention.

In parallel with that activity, the activities of our own DPC Working Group, will take us, well before that Climate Convention, to a position where we will be able to articulate responsible policies concerning stabilization, and concerning possible reduction. We can't predict at this time what, if any, reduction we can hope to accomplish because we simply don't have all the facts.

We certainly will be able to discuss these questions, however in a knowledgeable way, knowing both the science and the economics to the best extent possible. We simply didn't have the economics at Noordwijk and that is the major reason why we, and the Japanese, and the Soviets, felt that we could not go any further than we did.

Senator **Mikulski**. We were pretty honest and straightforward——

Dr. **Bromley**. Absolutely.

Senator **Mikulski** [continuing]. And fessed up that essentially we were not sure, and perhaps others agreed. Well, now, this Second Climate Convention, will that set the schedule then for reducing CO_2 do you think?

Dr. **Bromley**. I could not predict that. It will depend—a great many other countries in the interim between Noordwijk and this Second Convention, have become much more sensitized to the fact that they might not have been as wise as they might have appeared, to be prepared to agree to the rather stringent Noordwijk proposals. They are doing a lot of analyses and studies during this period as well.

Senator **Mikulski**. So, they are doing what we are doing?

Dr. **Bromley**. They are doing what we are doing.

Senator **Mikulski**. So, we have to wait until the Second Climate Convention.

Dr. **Bromley**. That's correct.

EDUCATION

Senator **Mikulski**. My last question really goes to education. I mean, there was a whole set of questions on research, and we will just get those over to you, but one of the things that clearly emerges is that in order to reach this scientific objective and all others that you really had in your responsibility, is that we need to have our people ready.

As we look toward the research book, we see that there was someone in the National Science Foundation involved, and they talked about the research centers and I won't go through that; and also Admiral Watkins' approach—I think he has really been quite innovative and encouraging personal and accredited laboratories to get out there and form a public/private partnership.

Dr. **Bromley**. He has.

Senator **Mikulski**. Now, one group, and you had everybody at the table, but I didn't see the Department of Education, and my question is, Where do they fit in, and have they gotten the message, or are they so obsessed with other things that we are losing sight of what we need to accomplish?

Because the National Science Foundation really develops model programs, and stimulates even research and how to communicate this, and will do some demonstration projects, but is the Department of Education really out there, from kindergarten on up.

Dr. **Bromley**. I am happy to be able to respond, Madam Chair. Just last evening, Erich Bloch, Secretary Cavatos, and I met to discuss a number of these questions, and I think I can say that we are going to be able to take care of a number of these issues that have been around for some time relating to the distribution by the Department of Education of NSF materials.

As you know, we at OSTP have been charged by the Congress with analyzing the efforts of the Department of Education and the National Science Foundation in the field of science and mathematics education; we are actively doing that, and we have the full cooperation of the Secretary and of Director Erich Bloch, and all their people. We expect to get that report into your hands at the end of February as required.

Senator **Mikulski**. Great. We are actually going to be early.

Dr. **Bromley**. Yes.

Senator **Mikulski**. If you will recall, Senator Garn, that is what we had requested; which is what are they doing, and are they doing it together.

Dr. **Bromley**. The second point that I would make is that through past oversight, as much as anything else, I and everybody else, including Secretary Cavatos, were rather distressed to find that the Department of Education was not a member of the Federal Coordinating Council for Science, Engineering and Technology.

DEPARTMENT OF EDUCATION NEEDS TO BE INVOLVED

One of the first things that I have on my slate is to get the legislative changes that are required to make the Department of Education a member of that group, so that the Secretary and many of his senior people will be actively involved in all our FCCSET committees, to make sure that the Department of Education really is tied into—and coordinated with—the educational activities of this Government.

Senator **Mikulski**. Well, change comes through a series of steps, and not a series of events, and I am actually delighted to hear that, and we will look forward to that report, and then I am over there on that Kennedy-Hatch authorizing committee, and we look forward to stimulating them in that direction.

I also chair a really small task force in the Kennedy Committee. Actually Senator Durenberger and I cochair on his work force, and we might then ask the three of you to just come and let us know, and just to close the hearing antidotally, there are 13,000 people working with the National Institute of Health in Maryland right this minute. That is not even Goddard and some of the other Federal jewels. If I take the combined work force of General Motors and Bethlehem Steel, that does not equal the number of people working at the NIH.

Now, that really says where our economy has gone. We could argue whether it should go that way, but still we are talking about opportunities in the future that it is going to be in these fields.

ADDITIONAL COMMITTEE QUESTIONS

We will submit the balance of the questions for response in the record.

[The following questions were not asked at the hearing, but were submitted to the Department for response subsequent to the hearing:]

QUESTIONS SUBMITTED BY SENATOR MIKULSKI

U.S. POLICY ON GLOBAL WARMING

SENATOR MIKULSKI: What level of global warming is acceptable to the Administration, 1 degree, 3 degrees, or something else?

ANSWER: An implication of this question is that below some threshold, such as 1 degree or 3 degrees, global warming is acceptable and no action needs to be taken. Conversely, above the threshold, any action that might reduce global warming would be warranted.

I do not believe that one can set such levels. There are a large variety of policy responses with differing costs and predicted efficacies. Administration policy is, and will be, based on a careful tradeoff between the benefits and costs of various policy options. Decisions need to be supported by analyses of both the economics of policy options and the predicted consequences of such actions upon the earth, including not only just temperature but also effects such as changing precipitation patterns and sea-level rise. Policies need to be flexible so that they can be reevaluated as new scientific results are obtained.

SENATOR MIKULSKI: How would you respond to critics who suggest that, in light of the Administration's slow action on policy, a billion dollars worth of research is really a delaying tactic to avoid the tough choices?

SENATOR LEAHY: According to the EPA, it is generally accepted current knowledge that in the 1980's, the United States contributed approximately 21 percent of the planet's greenhouse effect. This is far out of proportion with this nation's percentage of total world population. You stated in today's hearing that the U.S. is the world leader in translating global climate change research into public policy to address this complex web of problems. Given our enormous, disproportionate contribution to this situation, do you think the U.S. is where we should be in developing firm policy direction out of our research findings? Do you think that the "go slow" approach on policy development and action that Mr. Sununu recommends to the President is advisable in light of your understanding of the global change situation -- and especially the size of our contribution to it?

ANSWER: As I stated in my testimony, I believe that this Administration is doing more than any other country on the issues of global change, as measured by concrete actions, such as the commitment of resources to study the impact of both anthropogenic changes and the actions to reduce those changes. Tough choices will need to be made not only by the U.S., but by all the countries, and these choices should be made in an international arena. The Administration is ready to work with other countries, and we hope that the IPCC process and the President's offer to host the framework convention will lead to international agreements.

I do not accept the premise of the latter part of the question concerning Governor Sununu's alleged recommendations to the President. The Administration's policies have been developed with input from a wide variety of agencies and individuals and represent strong majority opinions and in most cases consensus among all concerned.

SENATOR MIKULSKI: If the Administration is not shying away from policy, can you explain why it has proposed cutting EPA's policy research on global warming by almost 40 percent?

ANSWER: The Administration is proposing a balanced policy and research budget for EPA that it believes is sufficient to fulfill the goals of the Agency in this area. This includes both identifying and evaluating possible strategies for limiting greenhouse gas emissions and providing EPA input to the U.S. delegation that will participate in international negotiations for a climate convention. The convention will begin soon after completion of the IPCC report next Fall. The Administration views these as critical functions and believes it has provided sufficient funding to meet EPA's objectives.

EPA's global change program budget for FY 1991 is a total of $43 million and 92 work years. This request includes both research and policy activities in the stratospheric ozone depletion and global climate change programs. The total budget request in FY 1991 provides sufficient funding for these programs. Funding for policy activities is $21.1M for FY 1990 and $17.41 for FY 1991. This decrease reflects the completion of two major reports on global climate change.

U.S. GLOBAL CHANGE RESEARCH

SENATOR MIKULSKI: How did the Committee on Earth Sciences come up with the current organizational scheme for global climate change research and what policy questions shaped how these areas were ranked in order of importance? Did the NAS concur in these research priorities?

ANSWER: The details of the planning process and the research plan are presented in the January 1989 report on the strategy and in the summer 1989 report on the research plan. Traditional science disciplines, such as oceanography and atmospheric chemistry, have been replaced by the seven science elements, such as biogeochemical dynamics, that span disciplines. The CES anticipates evolving from the science elements to a comprehensive earth system that models each of the science elements simultaneously.

Priorities were ranked so that the scientists' ability to predict the consequences to the earth system of action and inaction were maximized. They combine both the knowledge (and lack of knowledge) of the underlying processes and the scientific readiness to achieve results. They came from discussions within the CES and from previous work on the science of global change, both within the Federal government and outside. Specific references are given in the Research Plan.

The National Academy of Sciences' Committee on Global Change, chaired by Hal Mooney, reviewed the priorities in draft form. The CGC stated that the draft priorities were generally quite consistent with the priority areas of the IGBP and the CGC, although they expressed some reservation about the presentation of ranked priorities at all. They note, as does the CES, that a balanced program addresses all of the priority areas. At a recent meeting, the CGC agreed in principle with the general rankings and cited differences of a few minor points. Those comments will be included by the CES in the next draft of the research plan, which is expected to be completed by early summer.

SENATOR MIKULSKI: Why did the area of scientific research, that includes finding out the "sources" of greenhouse gases, particularly methane, receive both a smaller dollar and percentage increase than "climate and hydrologic systems"? When will we have a reliable set of data on methane emissions based upon the Administration's current research plan? How and why did the Committee on Earth Sciences decide that climate systems was the most pressing area of scientific inquiry, thus justifying an increase of 56 percent in the current budget?

ANSWER: Much of the concern scientists now share about global change is specifically directed toward earth system behavior over periods of a few years to several decades. Potential problems such as greenhouse warming, regional drought, and sea-level rise are examples of this concern about climate system behavior. The first of the CES science elements (Climate and Hydrologic Systems) treats the global scale, systematic behavior of the earth system on climate time scales. This element is complemented by work organized under the "Biogeochemical Dynamics" and "Ecological System and Dynamics" themes of the program.

These elements deal with an important set of processes which influence climate system behavior. A problem such as greenhouse warming must be viewed as involving all three of these elements. When viewed in this fashion, the CES priority structure for climate system, biogeochemical cycling, and ecosystems response to climate change represent a cohesive and balanced attack on a set of pressing problems.

The USGCRP methane research is focussed on several high-priority research areas, notably (1) wetland and rice emissions (2) isotopic studies to identify source regions, and (3) how emissions can change with climate change. These studies include field campaigns, laboratory investigations, and modeling. With the planned levels of support, these projects should produce a substantially improved methane emissions inventory in 3 to 5 years. In particular, on this time scale, the community should be moving toward a fledgling predictive capability regarding future methane abundance, rather than the extrapolative mode that we have now.

SENATOR MIKULSKI: What major gaps in our information will be filled by this research and what policy decisions will be shaped as a result?

ANSWER: Fundamental questions about how the earth system responds (on scales of years to decades) to changes in radiatively-active gases (such as carbon dioxide) or how and why persistent regional drought develops will ultimately be answered by the research program proposed in the CES plan. These scientific insights are expected to be a key piece of information in the policy formulation process for problems such as greenhouse warming (CO2 emissions), deforestation, U.S. agricultural policy and practices and regional water resources.

DATA MANAGEMENT

SENATOR MIKULSKI: How do we know our existing data from previous space and ground-based observation does not tell us all we need to know on global climate change?

ANSWER: We have profound uncertainties in many of the different aspects of the global change research program. The Research Plan presented in "Our Changing Planet: The FY 1990 Research Plan" describes in detail many of those scientific problems that are still unknown. There is also wide agreement in the scientific community that the simultaneous monitoring provided by the Earth Observing System will be important in understanding the physical processes. It is difficult to determine either trends or global values from most existing data because so much of it was taken at different times with different instruments.

SENATOR MIKULSKI: How does the current strategy plan to use this previously unused data?

ANSWER: First, much of the existing data is used and is very important in current scientific investigations, in calibrating new systems, and in checking new algorithms. On the other hand, some of the existing data is not currently used. In order to make use of previously unused data, agencies plan to fund various data recovery projects, for instance, to recover data sets from publications, manuscripts, and deteriorating storage media such as Fosdic cards and magnetic tapes. In fact, outside of the Earth Observing System Data and Information System efforts, the bulk of the FY 1991 data management funds for the U.S. Global Change Research Program is targeted for data base development. The FY 1991 Global Change Research Program Plan states that on a priority basis, data sets will be extended into the past, both to document global change and to test and validate diagnostic and predictive models. All agencies are providing data management resources for the development of historical data bases.

SENATOR MIKULSKI: Given our poor track record on using previous climate data, what steps do you plan to take so that any new data we gather is disseminated as widely as possible for scientific analysis?

ANSWER: I do not believe that our track record is poor; admittedly, we could always do better, particularly with the benefit of hindsight. Data access is the key toward better utilization of our existing data bases. In FY 1991, CES agencies are taking several major steps to better enable users to search for and obtain data. Through the Interagency Working Group on Data Management for Global Change, these agencies are preparing a "Data Management for Global Change Policy Statement." A key element of the policy addresses accessibility and timeliness of data for the assurance of timely availability of data to researchers within the context of applicable constraints.

Another key access element is the development of directories, catalogs, and inquiry systems. This is now being done via the Interagency Global Change Directory, which is part of an evolving system of national and international directories. The system should result in a master list of data sets relevant to global change studies. Also, part of the FY 1991 U.S. Global Change Research Program budget is devoted to the technology aspects of data access, such as making data sets more accessible on line, or on CD-ROM. In addition, roughly one third of the funds for NASA's Earth Observing System will be focused on the dissemination of data, including using the existing data.

SENATOR MIKULSKI: Could we prudently spend more money for this purpose in 1991? If so, on what?

ANSWER: More money could be spent on this issue as well as any of the other parts of the research plan. For example, there is still much data that exists but is unavailable for use. However, the overall request represents a balanced program at the appropriate levels.

EDUCATION

SENATOR MIKULSKI: Why isn't more effort devoted to education as part of this global change research effort, particularly for students at the pre-college level? When can we see a written blueprint on this education strategy, that focuses particularly on the pre-college student?

ANSWER: There is a large amount of effort being placed on pre-college, as well as more senior, students. The U.S. Global Change Research Program recognizes the need to develop the human resources and scientific talent to study the complex and inherently multidisciplinary problems of global change. NSF, DOE, and NASA have proposed major educational initiatives as part of their global change research programs in FY 1991. These programs will mostly support several hundred postdoctoral appointments, graduate students, and undergraduate students as research participants, as well as several summer institutes on interdisciplinary global change research problems. However, a component of the DOE educational initiative will address the pre-college level (K-12), primarily through teacher training programs and work on curriculum development at the DOE National Laboratories and the development of innovative science curricula dealing with global change topics.

Education efforts for FY 90 will include a post-doctoral program through a joint National Science Foundation and Department of Energy. This program is under development at the present time. A blueprint on the global change education strategy will be available when the detailed U.S. Global Change Research Program Plan is released in the spring of this year.

QUESTIONS SUBMITTED BY SENATOR LEAHY

SENATOR LEAHY: I note that $289 million or 77 percent of the $375 million total budget increase that the Administration is requesting for FY 1991 global climate change research is concentrated in three agencies -- the National Aeronautics and Space Administration, the National Science Foundation, and the National Oceanic and Atmospheric Administration.

Given what will be very tight budgetary constraints this year, this is an enormous increase for these three agencies. Offsets from other accounts within the agency will be required if the Appropriations Committee decides to pursue full funding for the global climate change request.

What intra-agency accounts does the Administration propose cutting to produce offsets to cover the $172 million NASA global climate change increase; the $48 million NSF increase; and the $69 million NOAA increase?

ANSWER: Prior to the development of the FY 1991 Budget, it was established that a research effort focused on reducing the scientific uncertainty associated with global change issues was a high-priority initiative within the Administration. As part of this recognition, it was decided that the U.S. Global Change Research Program was not to be funded at the expense of ongoing agency programs. This commitment has been effectively honored, and NASA, NOAA, and NSF agency budgets reflect responsive proposals not only to the USGCRP but also to the individual agency mission. Thus, I see no need to cut ongoing programs to fund global change research.

SENATOR LEAHY: I am impressed, and agree with the aggressive energy conservation policy that you advocate in your remarks before the subcommittee today.

But I see a gross inconsistency in the Administration's Department of Energy budget requests for energy conservation and technology improvement work in the areas of transportation; industrial technologies; and multi-sector research and development. In all three areas, the budget request for FY 1991 is markedly below the FY 1990 appropriated level.

I am particularly concerned that the Administration is once again requesting a phase out of all funding for the States for the Weatherization Assistance program, that is primarily of benefit to low-income citizens.

How do you explain this inconsistency between your enthusiasm for energy conservation as a means of stabilizing the global climate change situation, as the Administration's backing away from investing in improvements in these four important areas? And particularly, are we forgetting low-income Americans -- the people most hurt by the proposed $187 million cut in eartherization assistance -- and taking on this global climate change problem without thought for an initiative that both conserves energy and frees up some of the meager financial resources of the poor? Is global climate change policy, in practice, going to mean only expensive new technologies that the poor cannot afford?

ANSWER: This Administration believes that we have taken a careful and integrated approach to energy conservation policy in the four areas you mention. The FY 1991 budget request is more than double the amount requested for FY 1990 in conservation research and development. This is a budget that is responsive to future market needs and opportunities; is responsive to energy, economic and environmental goals; is balanced by end use and timeframe of delivery; and that will serve as a catalyst for progress in the private sector.

The budget requests in transportation, industrial technologies, and multi-sector research and development are lower than last year in appropriation, but much higher than the FY 1990 Administration request. This is due principally to completion of ongoing projects and to some specific choices we have made. In the Office of Industrial Programs, the reduction largely reflects the one-time funding spike caused last year by the ramp-up of the Metals Initiative. In the Office of Transportation, the reduction reflects our request for funding of only one automotive gas turbine team and the narrowing of our development process to the three most promising battery couples for electric vehicles. In the multi-sector area, the reduction is caused by a scaling down of materials investigations in this basic research area as the results are picked up within the applied research programs.

We are committed to the continuation and revitalization of State Energy conservation and weatherization efforts. In FY 1991, the State and local grants will be supported from funds derived from petroleum violation escrow (PVE) accounts under the terms of the Petroleum Overcharge Distribution and Restitution Act of 1986 (PODRA). We have chosen to leave to the States the level of resources that they wish to commit. At a time of fiscal constraints we think it inappropriate to put forth $200 million in Federal resources in additional State aid.

A new incentive initiative will be implemented in the Weatherization program. The initiative will provide funds to the States in two ways. First, $5 million will be awarded on a competitive basis to fund State proposals on innovative ways to implement weatherization activities. Second, $10 million will support leveraging at the State level of private sector funds for weatherization. Funds cut from these programs can be made up from the PVE accounts.

SENATOR LEAHY: I have worked with many bureaucracies in my years in the Senate, and am often amazed at the lack of even intra-agency communication -- not to mention that among multiple agencies. What systems do you have in place to assure the Appropriations Committee that the seven agencies working on the U.S. Global Change Research Program are communicating at a high level, fully sharing their findings -- and are capable of effectively using the very large increase in research dollars that the Administration would like them to have in FY 1991?

ANSWER: The Committee on Earth Sciences (CES) provides the principal focus for the interagency coordination and collaboration required for the successful implementation of the U.S. Global

Change Research Program (USGCRP). The Committee membership reflects the highest levels of scientific leadership in the member agencies and Departments (e.g., the Director of the National Science Foundation and the Administrator of the National Oceanic and Atmospheric Administration) and they have been actively involved at all stages in the evolution of the U.S. Global Change Research Program.

The CES has been so effective, in fact, that I am using it as a model for the revitalization of all the Committees of the Federal Coordinating Council on Science, Engineering and Technology, which is the principal mechanism that the Director of OSTP has for oversight of Federal scientific and technological programs.

The detailed development and day-to-day coordination of the USGCRP falls to the CES Working Group on Global Change. To a great extent, the success of the USGCRP is a reflection of the serious commitments CES member agencies have made. Working Group representatives are senior-level program managers who are responsible for the implementation of their agency's contributions to the national effort. They communicate on an almost daily basis with each other, with their CES principals and with scientists in and out of the Government. Representatives of the Office of Management and Budget and OSTP are active members of the Working Group and ensure the involvement of the Executive Office of the President on a close and continuing basis. Together, these individuals represent the Federal muscle which will carry the Program forward.

Throughout the development of the USGCRP, the Working Group members and the agencies they represent, demonstrated a remarkable willingness to critically review and revise their activities to achieve effective coordination and ensure that each agency is bringing its unique talents and capabilities to bear on the problem. I am convinced that the agencies of the Executive Branch are prepared to work together and with Congress to ensure the successful implementation of this high-priority Program Climate Systems.

QUESTIONS SUBMITTED BY SENATOR GRASSLEY

SENATOR GRASSLEY: You reference General Circulation Models in your testimony. Could you explain the purpose of these models in greater detail?

ANSWER: Questions about the future state of our environment, such as global and regional distributions of temperature, precipitation, and storm frequency; global sea level; water resources; and biological productivity, can best be answered through theoretically-based model simulations and predictions. Other than what we can learn from paleohistory, the multiple and complex earth-system processes and feedbacks cannot be assimilated and projected in any other practical way.

Theoretically-based general circulation models, or GCMs, are the only models that provide geographical distributions of these variables and hence, as they are further refined, regional predictions.

SENATOR GRASSLEY: How reliable are these models?

ANSWER: Today's global models simulate with acceptable certainty some of the important processes of global change, for example, the primary response of the climate system to increased atmospheric concentrations of greenhouse gases, i.e., atmospheric warming. However, equally important are the feedback processes activated by that primary response. Many of these are treated only in a rudimentary fashion by the models, e.g., cloud-radiative interactions, ocean circulations, surface fluxes, and biospheric interactions. The U.S. Global Change Research Program has established as its highest priority those research programs that address explicitly these weaknesses. The goal is to gain an understanding of Earth-system processes which, when applied to the development of global models, will reduce to acceptable limits the uncertainties of the model predictions.

SENATOR GRASSLEY: Do our current models accurately reflect past climate histories? In other words, looking backwards instead of forward, do the models give us numbers which reflect actual past world temperatures?

ANSWER: GCMs have had only moderate success reproducing past environmental conditions on earth. But although the examples of successful comparisons give us some confidence that the models are performing well, there are still significant disagreements that highlight important weaknesses in either the numerical simulations or in the paleodata. Some of the successes include: 1) the reproduction of the history of the monsoon in tropical Africa and southern Asia and 2) the reproduction of the precipitation history in southwestern United States during the last ice age. In each of these examples, a single factor tends to dominate the circulation regime: the strong influence of insolation that affects the land-sea heat distribution in southern Asia and Africa, and the existence of a 2 km ice sheet in North America during the last ice age.

Some of the failures in the model predictions include: 1) the poor reproduction of the vertical temperature distribution at low latitudes during the last glaciation; 2) poor reconstruction of the spatial temperature distribution at high latitudes during the last glaciation; and 3) the poor reproduction of the warmer earth which existed millions of years ago. This last comparison is important because it is necessary to invoke very high CO2 concentrations in the atmosphere to reconcile the differences. In each case, the poor model validation may result either from poor data quality or from poor numerical simulation if not, indeed, both.

SENATOR GRASSLEY: I need you to clarify one statement from your testimony for me. You indicate that sea-level rise projections have recently been reduced to one foot with a margin or error of 12-18 inches. Am I to interpret from this statement that we could see a drop in sea level of six inches? Or is current science simply too inexact to accurately measure this type of change?

ANSWER: There is enough uncertainty regarding predictions of future sea level that scientists are reluctant to predict positively that we will not experience a drop in sea level. The current predictions, however, tend to cluster around about a foot rise, with greater probability of a higher rise, such as two or more feet, than a lower rise or drop. Again the time scale is unknown in any detail but no significant change is anticipated in the next few decades.

SENATOR GRASSLEY: You mentioned at the beginning of your testimony that methane generated by agricultural practices is a major threat to our environment. Coming from an agricultural state, I, of course, am concerned about how this will effect my constituents. Have there been any proposals to regulate or tax the agricultural industry's emissions of methane? Do you see this type of action occurring at any point in the near future?

ANSWER: There are no proposals to regulate or tax methane emissions from agriculture, now or in the foreseeable future. First, we need much more research to understand the entire cycle of methane production from agricultural systems. We also need more research to determine how much methane is released from livestock and rice production in the U.S. as well as how much from natural woodlands, oil fields, coal fields or other minor sources. Scientists are also studying processes for reducing the emission of methane that will be economically viable for the agriculture and forestry sectors of the U.S. economy.

SENATOR GRASSLEY: It would seem that at least one course of action is clear. We are challenged today to generate more forested areas worldwide rather than decreasing the amount. Do you have any plans to see that this idea is communicated to the general public?

ANSWER: There are two courses of action being developed. The first is through the President's America the Beautiful program, to plant, maintain and improve an additional one billion trees each year in excess of the current programs. The educational program being developed through U.S. Department of Agriculture to support this program will provide information about the importance of these trees as they grow. The second is through the Intergovernmental Panel on Climate Change, Working Group on Response Strategies. This international organization has developed an implementation measure based on public education and information. This will provide guidelines to the member countries for communicating the importance of offsetting carbon dioxide through such activities as tree planting and improved management of existing forests.

SENATOR GRASSLEY: What can be done to foster local leadership and initiatives for reforestation without relying on Federal grants which, most likely, would achieve limited results?

ANSWER: The urban component of the President's America the Beautiful initiative is designed to depend mostly on awareness and information programs developed through the non-federal sectors. It is anticipated that federal involvement will be limited to startup grants and that the remainder of the costs, training and long-term maintenance programs come from local and community activities. We anticipate participation from private industry, community groups as well as from State and local governments.

CONCLUSION OF HEARING

Senator MIKULSKI. Well thank you very much Doctor. That concludes the hearing and the subcommittee stands in recess.

[Whereupon, at 11:40 a.m., Thursday, February 8, the hearing was concluded and the subcommittee was recessed, to reconvene subject to the call of the Chair.]

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